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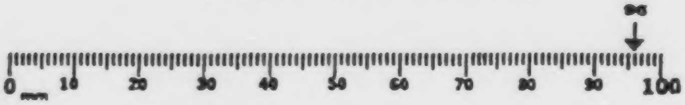

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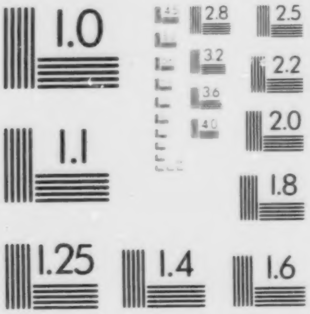

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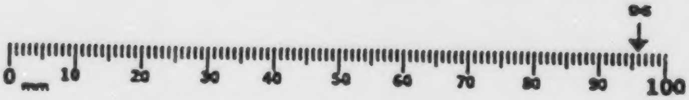

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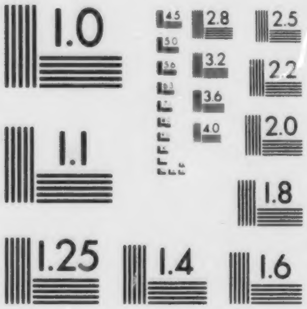

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GROUNDWATER IN ONTARIO:
HYDROGEOLOGY, QUALITY CONCERNS
AND
MANAGEMENT

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ABSTRACT

Groundwater forms an important source of municipal, industrial, agricultural and residential water supply in Ontario. Groundwater is available from a number of extensive bedrock aquifers in the Great Lakes and the Ottawa/St. Lawrence Lowlands and from sand and gravel aquifers found within glacial deposits in most parts of the province. The major aquifer units are discussed in terms of occurrence, groundwater availability, yield and water quality.

Groundwater quality is generally good in most aquifers in Ontario. However, many aquifers are poorly protected from near-surface contamination sources and as a result anthropogenic contamination has been found in several areas. The main concerns for water quality and groundwater management are waste disposal, agricultural activities, sewage disposal systems and road salt.

Provincial legislation relating to water resources and groundwater protection is summarized. The principal agency responsible for groundwater management is the Ministry of Environment and Energy, which monitors groundwater quality and quantity, maintains groundwater databases, enforces the well drilling regulations and assists in problems of groundwater supply and quality. In these and other tasks, the Ministry collaborates with provincial ministries such as Agriculture and Food, Natural Resources, Transportation and Health. The Ministry also shares responsibility for management of water in the Great Lakes Basin with other agencies in Canada and the United States.

RÉSUMÉ

En Ontario, les eaux souterraines constituent une partie importante de l'approvisionnement municipal, industriel, agricole et résidentiel. Ces eaux sont contenues dans un certain nombre de vastes aquifères du substrat rocheux situé aux Basses-Terres des Grands Lacs et de l'Outaouais/St. Laurent, ainsi que dans des aquifères de substrat de sable ou de gravier qu'on trouve dans des dépôts glaciaires à de nombreux endroits de la province. Les aquifères principaux font l'objet d'une discussion portant sur leur nombre, leur production, et le volume et la qualité des eaux qu'ils renferment.

La qualité des eaux souterraines est bonne dans la plupart des aquifères de l'Ontario. Cependant, beaucoup d'aquifères sont mal protégés des sources de pollution proches de la surface et, par conséquent, on y a trouvé dans plusieurs régions une pollution anthropique. Les problèmes principaux de qualité de l'eau et de gestion des eaux souterraines sont liés à l'enfouissement des déchets, aux activités agricoles, aux systèmes d'élimination des eaux usées et au sel de voirie.

On donne par ailleurs un résumé de la législation provinciale portant sur les ressources en eau et la protection des eaux souterraines. L'organization principal chargé de la gestion des eaux souterraines est le ministère de l'environnement and de l'énergie qui surveille la qualité et la quantité des eaux souterraines, garde à jour les bases de données, veille à l'application des règlements de forage des puits et aide à régler les problèmes d'approvisionnement et de qualité de l'eau. Pour l'exécution de ces taches et d'autres le ministère collabore avec d'autres ministères tel que l'agriculture et nourriture, les ressources naturelles, le transport et le santé. Le ministère partage aussi les responsabilités de la gestion de l'eau du bassin des Grands Lacs avec d'autres organizations du Canada et des États-Unis.

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INTRODUCTION

This report, "Groundwater in Ontario", describes the physical setting (hydrogeology and some other relevant information), the quality of groundwater and concerns for it (including some information on quantity and use), and the tools available for groundwater management and protection (i.e. the legislation, institutions and programs) in the province. It is one of a series of reports covering all ten provinces and two territories of Canada.

The report was produced jointly by the State of the Environment and the National Hydrology Research Institute of Environment Canada and the Groundwater Research Group of Scarborough College, University of Toronto. The support and assistance of many provincial and federal officials, who provided information and reviewed the results, is also acknowledged. It is primarily the provincial governments who are responsible for our water resources, and it is provincial officials who daily deal with groundwater matters. Without their support and collaboration the report would not have been possible.

This report, together with those for the other provinces and territories, has several purposes. For one, the twelve reports will form the basis for a forthcoming overview of groundwater in Canada. That overview will be part of the new effort of the federal government to report on the state of the environment of Canada, an effort tied to the goal of sustainable development in the country. For another, the report attempts to provide comprehensive information on the different concerns and activities related to groundwater in the province; thus it can be useful for anyone in the province involved with groundwater, be they the public, consultants, industry or different levels of government. In effect, the report can form a bridge between the different groups which will help them to better understand each others concerns, goals and endeavours. Finally we want to provide with this series of reports a description of how groundwater concerns are dealt with in the various jurisdictions in Canada. This may lead to increased awareness and may form the basis for future increased collaboration.

As will be apparent throughout this report, the "tools" for groundwater management turn out, as often as not, to be legislation, institutions, or programs for overall water management, or for the management of waste, pesticides etc., rather than for groundwater management alone. This may lie in the nature of groundwater management, suggesting that groundwater and its management should be considered as part of a larger picture rather than as an isolated concern.

We would like to thank the many provincial and federal officials for providing their guidance and support and sharing their knowledge with us. Particularly we would like to thank the Environmental Monitoring and Reporting Branch (formerly Water Resources Branch), the Science and Technology Branch (formerly the Waste Management Branch) , the regional offices of the Ontario Ministry of the Environment and Energy, and the National Water Research Institute and the Ontario regional office of Environment Canada. We feel that, because of this collaboration, this is a joint product of all concerned. The errors and omissions that still occur are our, the authors, responsibility.

PART 1 HYDROGEOLOGY

1.1 Physiography

From the Precambrian to the present, the surface features of Ontario are a product of over three billion years of geologic processes. Based on their geologic history and characteristics, four large physiographic regions may be distinguished: the Great Lakes Lowlands, the Ottawa-St. Lawrence Lowlands, the Canadian Shield and the Hudson Bay Lowlands (Figure 1).

1.1.1 Great Lakes Lowlands

The Great Lakes Lowlands of southern Ontario are part of the Great Lakes/St.Lawrence drainage basin south of the Canadian Shield. In this region, Paleozoic sedimentary rock, gently dipping to the southwest, overlies the Precambrian basement.

The bedrock consists of sequences of fine clastic sedimentary rock, mostly shales, and carbonates; the former are underlying lowlands and basins, the latter constitute bedrock highs and escarpments (Karrow, 1989). They are covered by extensive drift, that is commonly 30 to 60 m thick (Karrow and Occhietti, 1989).

Bedrock shows little relief except for the prominent topographic features of the Niagara Escarpment and the Oak Ridges Moraine (Figure 2). Produced by differential erosion, the hard dolomite of the Niagara Escarpment rises in New York near Rochester, skirts around the western shore of Lake Ontario and then continues north to the Bruce Peninsula in Georgian Bay (Chapman and Putnam, 1984). As it passes to the north, the Escarpment rises from a 90 m bluff along the south shore of Lake Ontario to the 250 m high Dundalk Uplands (Brown et al., 1968).

From the section of the Escarpment called the Caledon Hills, a great ridge of glacial sediments known as the Oak Ridges Moraine extends eastward for 200 km (Chapman and Putnam, 1984). The steeper southern slope of the Moraine ascends from an elevation of 120 m asl along Lake Ontario to over 300 m asl along its crest. The north slope has a much smaller gradient and gently ramps north to Lake Simcoe and Georgian Bay.

The Oak Ridges Moraine is one example of many physiographic features formed by the Wisconsinan ice sheet. The topography of the Great Lakes Lowlands has been shaped by the Wisconsinan ice sheet that began its retreat 14,000 years ago. Glacial processes resulted in the formation of moraines, abandoned spillways, drumlins, eskers, abandoned shorelines and clay plains. The landscape has not been significantly altered since the last glacial period (Chapman and Putnam, 1984). Evidence of glacial periods prior to the Wisconsinan appears in subsurface sediments.

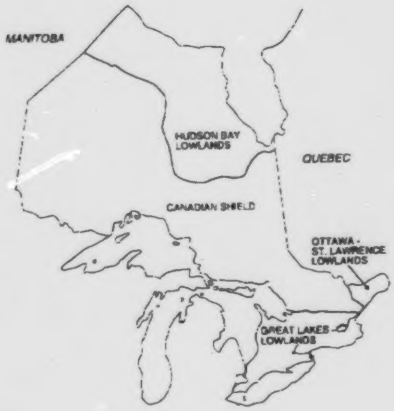

Figure 1: Major physiographic and hydrogeologic regions of Ontario.

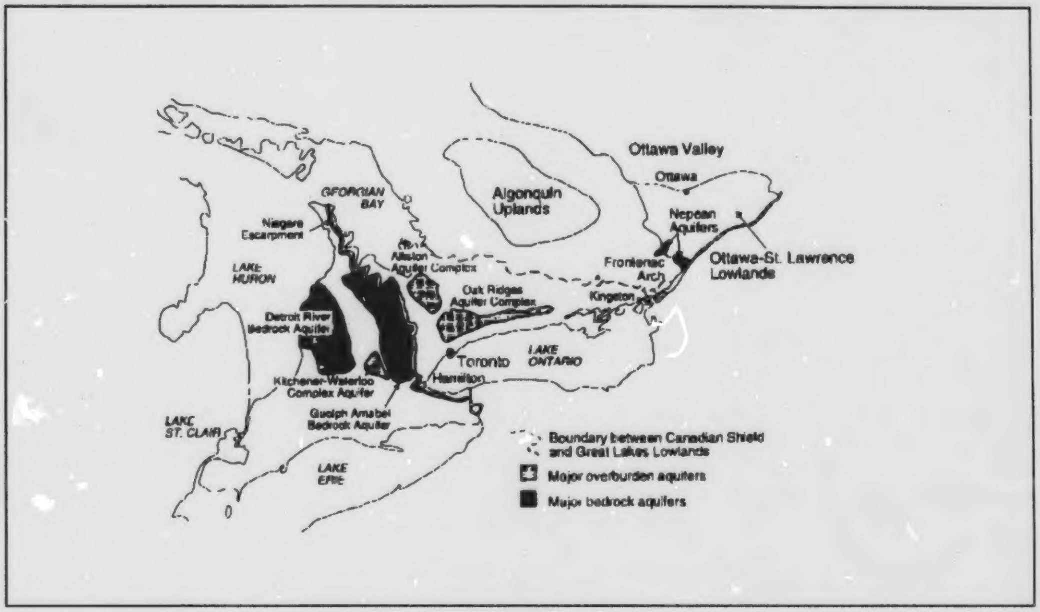
Ottawa Valley
Ottawa
Algonquin Uplands
Nepean Aquifers
Ottawa-St. Lawrence Lowlands
Frontenac Arch
Kingston
GEORGIAN BAY
Niagara Escarpment
Alliston Aquifer Complex
Oak Ridges Aquifer Complex
LAKE HURON
Detroit River Bedrock Aquifer
Toronto
LAKE ONTARIO
Hamilton
Kitchener-Waterloo Complex Aquifer
Guelph Amabel Bedrock Aquifer
LAKE ST. CLAIR
LAKE ERIE
Boundary between Canadian Shield and Great Lakes Lowlands
Major overburden aquifers
Major bedrock aquifers

Figure 2: Major physiographic and hydrogeologic features of southern Ontario.

1.1.2 Ottawa-St. Lawrence Lowlands

The Paleozoic bedrock of the Great Lakes and the Ottawa-St. Lawrence Lowlands is separated by the Frontenac Arch, a ridge of exposed Precambrian rock which joins the Canadian Shield to the Adirondack Mountains of New York State (Karrow and Occhietti 1989). It separates the two sedimentary basins near the outflow of the St. Lawrence River from Lake Ontario, east of Kingston; it also approximates the western limits of the late-glacial Champlain Sea.

The Ottawa-St. Lawrence Lowlands exhibit little relief except for the northwest trending fault scarps of the Ottawa-Bonnechere Graben. Plains of limestone bedrock capped locally by clay or sand overburden dominate the landscape (Chapman and Putnam, 1984). These are overlain by the marine deposits of the Champlain Sea.

The major physiographic and hydrogeologic features of southern Ontario, including the Great Lakes and Ottawa-St. Lawrence Lowlands, are shown in Figure 2.

1.1.3 Canadian Shield

Encompassing 63% of the province, the Canadian Shield is the largest of the physiographic regions. Erosional processes have peneplaned the Precambrian rocks of the Shield into a gently rolling landscape with relief that seldom exceeds 300 m. However, in localized areas rugged topography and prominent highlands do exist. The highest relief occurs on the eastern shores of Lake Superior, near Sault Ste. Marie, where the land reaches a height of 670 m asl.

In the vicinity of Thunder Bay in northwestern Ontario, Thunder Cape rises 380 m above the waters of Lake Superior (Hewitt and Freeman, 1972). In the southern part of the Shield, the Algonquin Park Uplands are an area of rough and elevated relief. The Uplands consist of a broad dome, rising eastward from Georgian Bay, and reaching a maximum height of 490 m asl in Algonquin Park. Eastward the elevations decrease to 180 m asl along the Ottawa Valley.

The Shield area contains four major surface water drainage basins that drain west from northwestern Ontario to Manitoba, north to Hudson Bay and James Bay, south to Lake Superior and Lake Huron, and southeast to the Ottawa/St. Lawrence Rivers (Ontario Ministry of Natural Resources, 1984). Covering approximately 18% of the surface of the Shield, surface water is easily accessible and more significant as a source of water than groundwater (Farvolden et al., 1988).

1.1.4 Hudson Bay Lowlands

The northeastern boundary of the Shield is flanked by the Phanerozoic carbonate rocks of the Hudson Bay Lowland. The carbonate rocks, ranging in age from Ordovician to Cretaceous, are overlain by glacial and marine clays. The Lowland is a muskeg covered plain with little relief and poor drainage (Hewitt and Freeman, 1972).

1.2 Climate

The climate of Ontario is primarily influenced by maritime polar and modified continental air masses from the north and west and by maritime tropical air from the south. The province is relatively shielded from Atlantic air masses (and storms) by the Appalachian mountain system. For about 30% of the time during winter, continental arctic air from the north brings very cold and dry weather. During summer, the maritime tropical air from the south brings hot and humid conditions for about 15% of the time (Phillips, 1990).

Within Ontario, local changes in climate are influenced by geographic factors such as latitude, relief, altitude and distribution of land and water. In particular, the presence of the Great Lakes provides one of the major climatic controls. By storing and exchanging heat with the atmosphere, the Lakes significantly moderate the temperature of the adjacent lands. The Lakes are warmer than the air in winter and colder in summer (Phillips and McCulloch, 1972).

Southern Ontario has a humid continental climate with warm summers, mild winters and a long growing season of 180 to 220 days. This portion of the province experiences a relatively large annual range of temperature from a high of 41 °C (recorded in Chatham, Hamilton and London) to a low of -45 °C in Algonquin Park (Brown et al., 1968). Across the region annual average precipitation varies between 660 and 1000 mm/a and is uniformly distributed throughout the year. Annual variations are due to the slope and elevation of the land, location relative to the Great Lakes and to prevailing wind direction. The highest values of annual precipitation are found on the slopes east of Lake Huron and Georgian Bay. These slopes are exposed to the prevailing moisture laden westerly winds. The relatively high elevations of the Dundalk Uplands of the Niagara Escarpment south of Georgian Bay are another area of high annual precipitation. Lying in the rain shadow of the Algonquin Park Uplands, the area southwest of Pembroke is the driest area in southern Ontario, receiving 660 mm/a.

In northern Ontario, mean daily summer temperatures (June and July) range from 12 °C in the extreme north to 18 °C in the south. In winter, mean daily temperatures range from -15 °C in the south to -28 °C in the north (Webber and Hoffman, undated). Mean annual precipitation varies from 1000 mm along the slopes facing Lake Superior to a low of 460 mm in the extreme north and northwest.

1.3 Recharge

Well hydrographs show that recharge occurs primarily during two periods of the year. Most recharge occurs during spring (April and May) and is associated with snowmelt. A second period frequently occurs in late fall and early winter when precipitation falls as rain and evapotranspiration is reduced because of colder temperatures.

Actual recharge to the groundwater flow system will vary with the permeability and thickness of the surficial materials. For example, annual recharge through the highly permeable sandy loam soil of parts of the Oak Ridges Moraine ranges from 280 to 380 mm. For the till plain south of the Oak Ridges Moraine annual recharge is reduced to a range of 150 to 200 mm (Singer, 1981).

1.4 Hydrogeology of the Great Lakes Lowlands

The variety of hydrogeologic environments of this region together with the wealth of available hydrogeologic information and extensive groundwater use, has made it useful to subdivide this region into three subregions for the purpose of this discussion:

(1) the **Southwestern Area**,
(2) the **West Central Area**, and
(3) the **South Central Area** (Figure 3).

1.4.1 Southwestern Area

This area is delineated by bedrock consisting of Devonian carbonates and shales, located south and west of the older Silurian bedrock of the West Central Area (Figure 4). The northeast part of the area is underlain by the limestones and dolomites of the Dundee Formation and the Detroit River Group. Both of these units also subcrop south of Lake St. Clair in the extreme southwest of the province. Between the carbonates are the grey and black shales of the Hamilton, Kettle Point and Port Lambton formations (Hewitt and Freeman, 1972).

A dominant hydrostratigraphic unit in this area is the St. Clair clay plain. Several extensive buried and surficial (sand plains) granular deposits also occur and form significant aquifers.

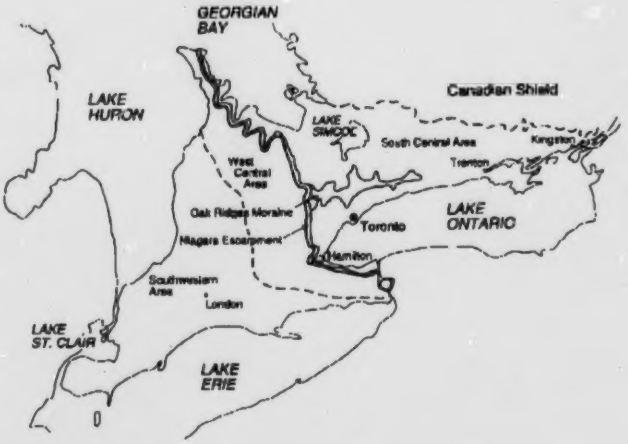

Figure 3: Hydrogeologic areas and major features of the Great Lakes Lowlands.

1.4.1.1 Bedrock

The Dundee Formation and the Detroit River Group are the major bedrock aquifers. The Detroit River Group, which includes the Lucas and Amherstburg Formations, is the most permeable (Goff and Brown, 1981), and consists of fine crystalline limestone, minor sandstone and granular dolomite (Brown, 1967). The Dundee Formation consists of light grey limestone with dolomite (Wang, 1986a).

The well yields of the two aquifers depend on secondary permeability and porosity of interstitial openings produced by fracturing and dissolution. The Detroit River Group is widely exploited for domestic, municipal and industrial uses (Goff and Brown, 1981). Yields usually vary from 0.8 to 3.8 L/s but greater yields do occur, with a maximum yield of 151 L/s reported for an industrial well near Goderich (Wang, 1986c). In the area around Walkerton, pumping tests of municipal wells indicate transmissivities about 10^{-4} m^2/s (Wang, 1986a). The Dundee Formation is also widely exploited although it generally yields less than 0.8 L/s.

The grey and black shales of the Hamilton, Kettle Point and Port Lambton formations yield low quantities of poor quality water (Mellary and Kilburn, 1968). Where sufficient yields are not available in the overburden, the Kettle Point Formation has been used to supply a fraction of a litre a second (Goff and Brown, 1981).

The Detroit River Group and the Dundee Formation are also used as aquifers south of Lake St. Clair. The upper portions of the Detroit River Group yield plentiful supplies for irrigation, but the water is sulphurous in places. A large percentage of wells in the Dundee Formation are dry or have high levels of sulphur and total dissolved solids (Mellary and Nakashiro, 1970). Mineralization of the groundwater increases with depth (Wang, 1986 a,c).

1.4.1.2 Overburden

The stratigraphy of the overburden can be broadly grouped into three hydrostratigraphic units. This grouping has been introduced by Gartner Lee and Associates (1984) to characterize the extremely complex hydrostratigraphic units in the South Central Area (see section 1.4.3.2) but can be used to describe the hydrogeology of all of southern Ontario. The deepest and most important of these units has been labelled "buried granular deposits"; it consists of sands and gravels, intermittently separated by silts and clays. The other two units are glacial till and surficial granular deposits.

In the Southwestern Area the stratigraphy of the overburden is extremely complex. While there is a rough sequence of two sand and gravel units,

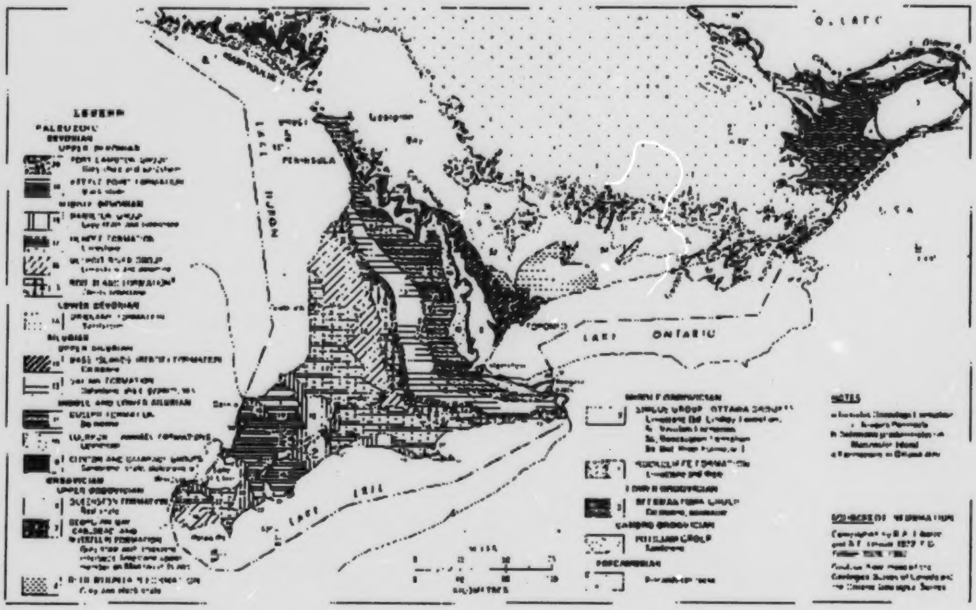
LEGEND
LAKE HURON
Georgian Bay
LAKE ONTARIO
LAKE ERIE
U.S.A.

Figure 4. REGIONAL BEDROCK GEOLOGY OF GREAT LAKES LOWLANDS

Figure 4: Bedrock geology of southern Ontario.

separated by clay and clay till units, the grouping introduced by Gartner Lee and Associates (1984) is less useful than in the South Central Area. Nevertheless it is used here for consistency.

Buried Granular Deposits

The majority of wells in the southwest obtain water from either a basal sand and gravel unit that lies directly on the bedrock, or from the upper 1 m of the bedrock (Mellary and Kilburn, 1968, 1969; Mellary and Nakashiro, 1970; Mellary and Novakovic, 1971). This basal sand and gravel aquifer is confined by 20 to 45 m of clay of the St. Clair clay plain (Farvolden and Cherry, 1988). Although common, its potential as an aquifer is limited by its thickness which varies from less than a metre to 6 m (Mellary and Kilburn, 1968; Gartner Lee and Associates, 1982). Where the saturated portion of the basal unit is thick enough, it yields from 0.8 to 3.8 L/s. Many wells in the basal unit are constructed to receive water from both overburden and bedrock.

Water quality from the basal unit is variable, ranging from poor to acceptable. The water is hard, usually exceeding the recommended concentration of iron, and sometimes those of chloride and fluoride. In Elgin county, the water often contains hydrogen sulphide (Mellary and Novakovic, 1971).

In the vicinity of London, buried granular aquifers occur at depths of 30 to 60 m. These are excellent aquifers, capable of yielding fresh water at rates of 15 to 50 L/s. They are protected from potential surface contamination by the thick overlying glacial tills. The City of London used such aquifers for its municipal supply until 1967. Water is now supplied by pipeline from Lake Huron.

In the London to Woodstock area, the buried granular aquifers are found at depths of 15 to 35 m. These are also excellent aquifers, protected by overlying till and usually yielding 0.16 to 3.8 L/s, although higher yields occur locally (Goff and Brown, 1981).

Clay and Glacial Till

In the counties of Lambton, Essex and Kent, clay of the St. Clair clay plain is the dominant hydrostratigraphic unit. Although the clay is described as fairly homogeneous, it has been divided into two layers on the basis of content of carbonates and engineering properties such as shear strength (Dreimanis, 1970). Near Sarnia where the total thickness of the clay is 41 m, the layer at the surface ranges from 14 to 18 m in depth. Usually, the surface layer lies directly over the deeper one, but in some areas pockets of silty sand (up to 4 m thick) lie between the two (Quigley and Ogunbadejo, 1976).

The upper 3 m of the clay have undergone weathering by physical, geochemical and biological processes. Within the weathered zone, fractures and root holes are common; they become scarce a few metres from the surface. The flow of water through the fractures of the weathered zone is the dominant method of groundwater movement. The maximum depth of the active flow zone varies from 5 m to more than 10 m in some areas (Ruland et al., 1991). Local residents have dug large cistern type wells in the weathered zone to provide domestic supplies of water (Richards, personal communication, 1991).

Below the weathered zone, the hydraulic conductivities of the clay are in the range of 10^{-10} to 10^{-9} m/s; this severely impedes groundwater movement. Movement of groundwater is estimated to be 10^{-4} to 10^{-3} m/a and isotopic data suggest that deep water in the clays may be 9,000 to 10,000 years old (Farvolden and Cherry, 1988; Gartner Lee and Associates, 1982).

Surficial Granular Deposits

Two small sand plains, one located west and the other east of London, cover a total area of 800 km^2 (Chapman and Putnam, 1984). The Caradoc sand plain is formed by the confluence of two proglacial deltas to the west of London. The fine surficial sand has been blown into sand ridges and dunes up to 10 m thick. The water table is usually shallow and varies from 3 to 5 m below the surface; the hydraulic conductivity is about 10^{-5} m/s. The Caradoc sand plain is underlain by a clayey silt with a low hydraulic conductivity in the range 10^{-10} to 10^{-9} m/s (Gartner Lee and Associates, 1982).

The sand plain to the east of London is stratigraphically more complex, consisting of sands interbedded with glacial tills. This area originated as a small lake basin into which glacial spillways discharged muddy water and laid down beds of silt and fine sand (Chapman and Putnam, 1984). Saturated sands are thick enough to yield domestic supplies; they may be unconfined or may be confined by glacial till. The hydraulic conductivity of the surficial sands and gravels range from 10^{-5} to 10^{-1} m/s (Gartner Lee and Associates, 1982).

The Norfolk sand plain is southeast of London. The sands and silts of the plain are deltaic and deposited by glacial meltwater discharged from the Grand River (Chapman and Putnam, 1984). The sand plain is commonly 3 to 10 m thick, in some areas up to 18 m thick, and is underlain by clay and silt. It covers approximately 3,300 km^2. Composed predominantly of fine sand, with some coarse sand and silt, the sand plain forms an unconfined aquifer capable of providing groundwater for domestic use (Gartner Lee and Associates, 1982). The hydraulic conductivity of the sand ranges from 10^{-5} to 10^{-4} m/s. The water is very hard (Mellary and Novakovic, 1971).

The Bothwell sand plain, located east and north of Chatham, is also deltaic in origin. In this case the Thames River deposited a thin sheet of sand on top of silty clay tills. The thickness varies between 3 and 10 m and the approximate areal extent is 1,900 km^2 (Chapman and Putnam, 1984). The water table is 1 to 2 m below the surface and the hydraulic conductivity ranges from 10^{-6} to 10^{-5} m/s. The aquifer of the Bothwell sand plain is thick enough to provide sustained yields for domestic wells.

Other, less extensive areas of surficial granular deposits are found in the northern part of the area. These deposits are hummocky, kame-like deposits that are part of the Horseshoe Moraines. They form unconfined aquifers that can provide quantities of water to meet domestic requirements (Gartner Lee and Associates, 1982).

1.4.2 West Central Area

The extent of this area has been defined by the subcrop of the carbonate bedrock of Silurian age which is found in a 90 km wide band west of the Niagara Escarpment (Figure 4). The bedrock formations include the Lockport-Amabel, Guelph, Salina and Bass Islands Formations. The Lockport-Amabel Formation is known as the "Lockport" in the Niagara Peninsula, and as the "Amabel" throughout the area north of Hamilton.

This area is not only distinguished by the presence of the Guelph-Amabel aquifer, one of Ontario's most extensive bedrock aquifers, but also by one of Canada's most productive overburden aquifers in the Kitchener-Waterloo area.

1.4.2.1 Bedrock

Guelph-Lockport Aquifer

In the Niagara Peninsula the primary bedrock aquifer is formed by a combination of the Guelph and Lockport Formations (Figure 5), which have a combined thickness of 67 m in the vicinity of Niagara Falls. The Guelph Formation is a brown, finely crystalline dolomite with interbedded grey shale and is about 37 m thick; the Lockport Formation consists of three dolostone and limestone members and is about 30 m thick (Novakowski and Lapcevic, 1988).

In the presence of fractures, hydraulic conductivities are about 10^{-4} m/s; otherwise, the hydraulic conductivity is extremely low at 10^{-11} to 10^{-8} m/s. In general, secondary permeability is most significant in the upper 3 m of the aquifer. Although yields may be increased by drilling deeper, there is a general decline of water quality with depth. Most of the aquifer only yields 0.4 to 0.8 L/s, but some areas can yield as much as 15 L/s if sufficient drawdown is available. The water levels are generally 0 to less than 9 m below surface (Turner, 1978d).

The water is a calcium sulphate type and very hard; it tends to become more saline near the bottom of the Lockport. The concentration of total dissolved solids increases from a potable 500 mg/L at the top of the Guelph Formation to 6,000 mg/L at the top of the Lockport Formation (Novakowski and Lapcevic, 1988). Although generally of marginal quality, the water is being used for domestic purposes. Occasionally, water treatment systems are used to remove high concentrations of iron (Turner, 1978d).

Guelph-Amabel Aquifer

The Guelph-Amabel aquifer is an extensive regional bedrock aquifer, extending from Hamilton to the Bruce Peninsula. High-capacity wells have been developed to supply large quantities of water for several municipalities and industries, and for irrigation. The two formations that comprise this aquifer, the Guelph Formation and the underlying Amabel Formation, consist of massively bedded dolomite which contains numerous biohermal reefs (Turner, 1978b). The permeability is primarily due to fracturing and chemical dissolution. The aquifer is confined by overburden which ranges in thickness from 5 to 30 m.

The combined thickness of the Guelph and Amabel Formations increases from about 90 m near Hamilton to a maximum of 120 m near Owen Sound (Turner, 1978 a-c). Specific capacities have an average range of 0.25 to 1.25 L/s/m (Wang, 1983). Municipalities obtaining their water supplies from the aquifer include Guelph, Cambridge, Fergus and Markdale.

At Guelph, the extensive sands and gravels of the overburden and the underlying Guelph and Amabel Formations act as a single hydraulic unit which provides large quantities of good quality water (Sibul et al., 1980). The transmissivity of this unit is 10^{-2} m^2/s and one well is capable of yielding 63 L/s (Jeffs and Hore, 1972; Turner, 1978b). In all other areas, yields from the bedrock range from 0.8 to greater than 3.8 L/s depending on available

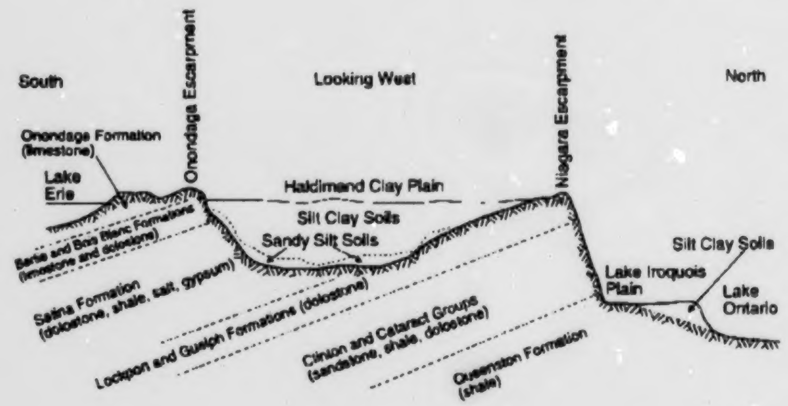
South
Looking West
North
Onondaga Escarpment
Niagara Escarpment
Onondaga Formation (limestone)
Lake Erie
Haldimand Clay Plain
Silt Clay Soils
Sandy Silt Soils
Bertie and Bois Blanc Formations (limestone and dolostone)
Salina Formation (dolostone, shale, salt, gypsum)
Lockport and Guelph Formations (dolostone)
Clinton and Cataract Groups (sandstone, shale, dolostone)
Queenston Formation (shale)
Silt Clay Soils
Lake Iroquois Plain
Lake Ontario

Figure 5: Cross sectional sketch through eastern Niagara Peninsula (from Gartner Lee and Associates, 1984)

drawdown, which is usually in the range of 15 to 30 m.

In the Blue Springs area near Guelph, the large range of transmissivities in the shallow bedrock aquifer and a groundwater divide that does not coincide with the topographic divide are indications of karst solution channels and conduits (Coward and Barouch, 1978). This contrasts with the area north of Owen Sound on the Bruce Peninsula where low specific capacities indicate relatively poor development of secondary permeability (Wang, 1983).

Quality of the groundwater from the Guelph-Amabel is suitable for all purposes. The water is a calcium bicarbonate type, slightly alkaline and generally very hard; it frequently contains excessive iron. The local occurrence of gypsum in the aquifer has resulted in variable concentrations of sulphate in the water (Golder Associates, 1991). Proximity to the Salina Formation is another factor controlling sulphate concentration. High concentrations of sulphate and hydrogen sulphide have been reported where the Guelph-Amabel is overlain by the Salina Formation (Turner, 1978c).

Salina Formation

The Salina Formation consists of dolomite with minor limestone and thin beds and lenses of anhydrite, gypsum and salt (Mellary and Aaltonen, 1973). In the south, well yields are generally less than 3.8 L/s with the exception of the municipal well at Caledonia, where the yield is greater than 16 L/s. North of the Kitchener-Waterloo area, the Salina is a high-yielding aquifer capable of yields greater than 16 L/s (Sibul et al, 1980).

Groundwater from the Salina is highly mineralized. The majority of wells in the Salina yield water with more than 2,500 mg/L of total dissolved solids and excessive sulphate at concentrations over 1,000 mg/L. The water is a calcium sulphate type, is very hard and usually contains high iron concentrations (Mellary and Aaltonen, 1973).

1.4.2.2 Overburden

The grouping of buried granular deposits, glacial till and clay and surficial granular deposits introduced by Gartner Lee and Associates (1984) is used to describe the hydrogeology of the overburden

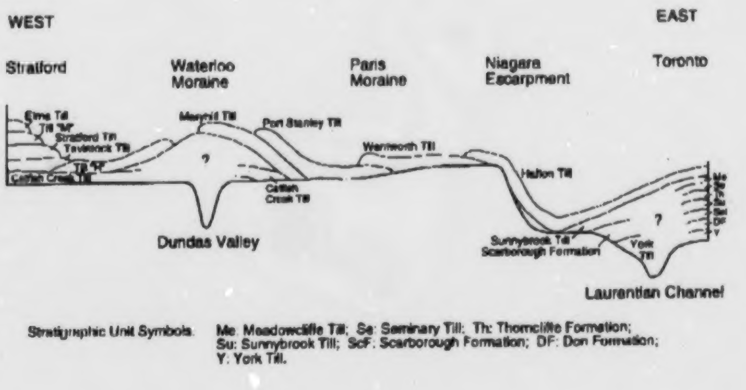
WEST
EAST
Stratford
Waterloo Moraine
Paris Moraine
Niagara Escarpment
Toronto
Elma Till
Till "M"
Stratford Till
Tavistock Till
Till "F"
Catfish Creek Till
Maryhill Till
Port Stanley Till
?
Wentworth Till
Catfish Creek Till
Halton Till
Dundas Valley
Me
Se
Th
Su
ScF
DF
Y
?
Sunnybrook Till
Scarborough Formation
York Till
Laurentian Channel
Stratigraphic Unit Symbols.
Me: Meadowcliffe Till; Se: Seminary Till; Th: Thorncliffe Formation;
Su: Sunnybrook Till; ScF: Scarborough Formation; DF: Don Formation;
Y: York Till.

Figure 6: Regional cross sectional sketch of Quaternary deposits, Stratford to Toronto (from Karrow, 1974)

of the West Central Area. Figure 6 is a cross sectional sketch of Quaternary deposits from Stratford to Toronto.

Buried Granular Deposits

In the Niagara Peninsula the buried granular deposits vary considerably in thickness and lateral extent. Where they are saturated, these deposits are capable of yields beyond those required for domestic supplies. The most extensive aquifer formed from these deposits is the Fonthill kame-delta. Located within a bedrock valley, the Fonthill kame consists of more than 120 m of sand and gravelly sand. It is a topographic high and forms a major groundwater recharge zone. The hydraulic conductivity of the sand is estimated at 10^{-5} m/s with a porosity of about 30% (Gartner Lee and Associates, 1984).

The water supply of the Regional Municipality of Waterloo is provided by aquifers that are among the best groundwater producing units in Canada (Committee on Regional Water Issues, 1990). The aquifers consist of kame, outwash, glaciofluvial and glaciolacustrine sands and gravels (Jeffs and Hore, 1972). A major source of groundwater recharge in the area is provided by the Waterloo Moraine, the primary topographic feature of the area. Recharge rates are greatest near the crest of the moraine and will vary with the permeability of the surficial material. Estimates of recharge range from 12 to 150 mm/a, depending on whether there is till or granular material at the surface. Located on the west side of Kitchener-Waterloo, the moraine is composed of kame and associated outwash sands and gravels with numerous interbedded tills (Water and Earth Science Associates Ltd., 1989).

The sand and gravel aquifers grade laterally into silts and clays and are interbedded with numerous glacial tills which act as aquitards. This produces a complex stratigraphy and a multi-aquifer system that is 100 m thick in some places. Delineation of the aquifers is a difficult task. Water and Earth Science Associates Ltd., (1989) recognize two major aquifers in the region. Jeffs and Hore (1972) and the Committee on Regional Water Issues (1990) subdivide the deeper aquifer into two and recognize a total of three major aquifers (Figure 7). The majority of wells are in the deeper aquifer which is confined by two till units. Pumping tests and groundwater modelling have shown this aquifer to be laterally extensive. Different water bearing zones can be differentiated, and lenses of low permeability within the aquifer can become locally significant aquitards. The upper part of the deep aquifer consists of outwash gravels and ice-contact deposits with transmissivities ranging from 10^{-3} to 10^{-2} m^2/s.

The topmost aquifer is a glaciofluvial deposit of gravel and sand that ranges in thickness from 15 to 20 m. The potential of this aquifer is limited by the low water table which reduces the saturated thickness to less than 3 m (Water and Earth Science Associates Ltd., 1989). This aquifer may be contemporaneous with the upper Mannheim, which is part of the largest and most productive aquifer in the region. (Committee on Regional Water Issues, 1990). There are several well fields that abstract groundwater from the various aquifers to supply the cities of Kitchener and Waterloo with good quality water. Individual wells within the wellfields are capable of yielding up to 76 L/s. Altogether the well fields produce a total of approximately 1,875 L/s (Water and Earth Science Associates Ltd., 1989).

Other sand and gravel aquifers occur in the surrounding area. An extensive sequence of medium to coarse sand and gravel 7.5 to 9 m thick is found east of Cambridge. Overlying the bedrock and hydraulically connected with it in many places, this aquifer is generally 24 to 36 m deep and is confined by lacustrine sediments and tills. Estimated yields from high-capacity wells are greater than 16 L/s. In the vicinity of Elmira similar deposits up to 24 m thick at a depth of 27 to 33 m also have the potential to yield more than 16 L/s (Sibul et al., 1980).

Glacial Clays and Tills

In the Niagara Peninsula the overburden is relatively thin near the Niagara Escarpment but it thickens to the south in a broad depression caused by erosion of the Salina Formation. The thickness of the overburden reaches a maximum of 45 m near the base of the Onondaga Escarpment, a low north-facing scarp that marks the southern boundary of the broad depression. The silts and clays between the Niagara and Onondaga Escarpments form the physiographic region known as the Haldimand clay plain which occupies almost all of the Niagara Peninsula (Figure 5) (Chapman and Putnam, 1984).

The Haldimand clay plain is the dominant hydrogeologic unit in the area. Local lenses of fine sand and seams of granular material do occur, but they are of such limited extent that they are not capable of sustaining adequate well yields. The silts and clays have extremely low hydraulic conductivities of about 10^{-10} to 10^{-9} m/s and seriously impede groundwater flow (Gartner Lee and Associates, 1982, 1984). Below the silts and clays, the Wentworth till underlies most of the area and although it has a greater hydraulic conductivity of 10^{-7} m/s, it is not a good aquifer.

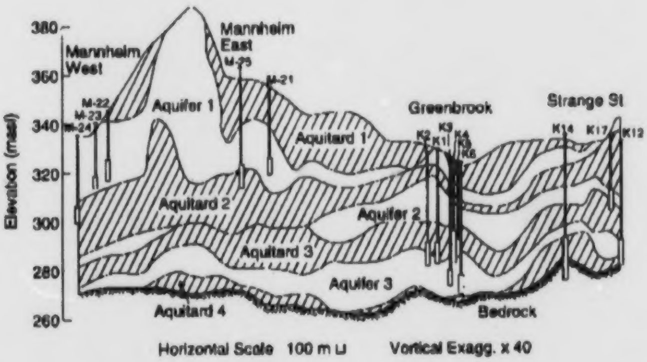

Figure 7: Cross sectional sketch through Region of Waterloo well fields (from Committee on Regional Water Issues, 1990).

Surficial Granular Deposits

An area of important surficial deposits lies north of the region of Waterloo. The relatively rough topography of this area comprises sands and gravels of kame moraines, outwash plains, and spillways, interspersed with more smoothly moulded till plains and drumlinized areas (Chapman and Putnam, 1984).

The irregular relief between the moraines and drumlins can vary by more than 30 m. Thickness of the overburden ranges from 0 to over 50 m in the kame areas (Gartner Lee and Associates, 1982). Yields for wells in the sands and gravels range from 0.16 to 3.8 L/s (Wang, 1983).

1.4.3 South Central Area

This hydrogeologic region is bounded to the west by the Niagara Escarpment, to the northeast and east by the Canadian Shield, to the northwest by Georgian Bay, and to the south by Lake Ontario. The major physiographic and hydrogeologic feature in this area is the Oak Ridges Moraine, the 200 km long ridge of glacial sediments located north of Toronto. Many aquifers and aquifer systems have also been identified north and south of the moraine.

1.4.3.1 Bedrock

The bedrock of the South Central Area consists of Ordovician shales and limestones which dip to the southwest. The eastern half of the region is underlain by the limestones of the Simcoe Group which include the Lindsay, Verulam, Bobcaygeon and Gull River Formations. In the very east of the region, there are isolated occurrences of sandstone of the Nepean Formation (also known as the Potsdam Formation) and shales and arkoses of the Shadow Lake Formation. The western half is underlain by shales of the Queenston, Georgian Bay and Whitby Formations.

The top of the bedrock is an erosional surface consisting of a complex system of bedrock channels and highs. The highest bedrock elevations occur as a ridge beneath the Oak Ridges Moraine (Sibul et al., 1977). The northeast-southwest trending bedrock channels were a drainage system prior to the development of the Great Lakes. A major bedrock depression that was once a regional drainage system from Georgian Bay to Lake Ontario is known as the Laurentian channel. From Georgian Bay the Laurentian channel parallels the Niagara Escarpment to meet Lake Ontario beneath Metropolitan Toronto (Figure 6) (Eyles et al., 1985).

In general, the shales and limestones of the region are poor aquifers, producing small quantities of poor quality water. Hydraulic conductivity can be extremely low ranging from 5×10^{-14} to 7×10^{-9} m/s, with most hydraulic conductivities being in the range of 10^{-13} to 10^{-12} m/s (Intera Technologies, 1987b). The availability and quantity of groundwater depends on secondary permeability, caused by interstitial openings such as fractures, solution channels and bedding planes. Wells are usually completed in the upper few metres of the weathered and fractured bedrock; they are capable of producing domestic water supplies (Funk, 1979). Vertical leakage from the overlying overburden can contribute significantly to bedrock groundwater supplies.

Along the south shore of Lake Ontario, the east-west strip bounded by the Niagara Escarpment and Lake Ontario is underlain by the Ordovician red shale of the Queenston Formation. Since overburden of this area is thin, the Queenston Formation is the primary source of groundwater (Ostry, 1979a). Although a poor aquifer, a well may yield a domestic water supply from the upper 3 to 6 m where the shale is weathered and fractured. The specific capacity of wells range from 10^{-3} to 10^{-1} L/s/m with hydraulic conductivities about 10^{-6} to 10^{-5} m/s. The quality of water from the Queenston Formation is often poor, with high concentrations of total dissolved solids, sulphate, chloride and sodium (Funk, 1979).

From Hamilton to Trenton, the overburden of the north shore of Lake Ontario thickens considerably relative to that of the Niagara Peninsula and becomes the predominant source of groundwater. In many areas the hydraulic head values from wells ending in overburden are similar to the head values from wells ending in the upper portion of the bedrock. It has been suggested that in these areas the overburden and the uppermost part of the bedrock are hydraulically connected forming a single hydrogeologic unit (Ostry, 1979 a, b; Ostry and Singer, 1981). However, in some areas where clay overlies the bedrock, the overburden and bedrock are separate aquifers (Hillier, personal communication, 1991).

Water wells have been completed in the shales of the Georgian Bay and Whitby Formations where overburden is thin. The shales of both formations have similar properties with yields of 0.08 to 0.20 L/s and hydraulic conductivities from 10^{-8} to 10^{-6} m/s (Funk, 1979; Hickinbotham, 1979; Sibul et al., 1977; Singer, 1974, 1981).

Water from these shales is a sodium bicarbonate type. Water quality is usually poor with elevated concentrations of total dissolved solids and natural gas. It can also be salty and/or sulphurous (Sibul et al, 1977; Wang, 1986b).

The limestones of the Simcoe Group can be an important source of water, particularly in the eastern portion of the Great Lakes Lowlands. East of Trenton, on the Napanee plain, the overburden becomes quite thin (Chapman and Putnam, 1984). The depth to the static water level is 3 to 4 m. Yields average about 0.15 L/s but can be greater in bedrock lows where thicker overburden contributes to yield. The hydraulic conductivity of the limestone is 10^{-6} to 10^{-5} m/s.

Other bedrock sources of water in the eastern portion are the sandstone of the Potsdam Formation and the basal arkoses of the Shadow Lake Formation (Sibul et al, 1974; Ostry and Singer, 1981). In the Lake Simcoe area, wells completed in the Simcoe Group and Shadow Lake Formation, adjacent to major water bodies (Lake Simcoe, Georgian Bay), have substantial yields. In such areas, fractured bedrock, hydraulically connected to the surface water, allows yields of 0.8 to 4 L/s (Turner, 1982a). The highest yield of 5 L/s is from the Canington municipal well completed in the Lindsay Formation (Wang, 1986b).

Water from the limestones of the Simcoe Group is a calcium bicarbonate type. The concentration of total dissolved solids increases from the recharge to the discharge areas; it can also be higher in deeper wells. The concentrations of other chemical constituents such as nitrate, phosphorus and iron may vary considerably (Funk, 1977a).

1.4.3.2 Overburden

This section is divided into subsections on buried granular deposits, glacial till, and surficial granular deposits; the subsection on buried granular deposits is further subdivided into descriptions of the Oak Ridges Moraine, the deposits of the Lake Ontario shore (south of the moraine), and those of the Simcoe area (north of the moraine).

Buried Granular Deposits

Oak Ridges Moraine

The granular material of the Oak Ridges Moraine was deposited during a retreat of the Wisconsinan glacier 13,000 years ago. Meltwaters became trapped between two retreating ice lobes, resulting in the deposition of up to 100 m of glacial outwash and deltaic sequences of sands and gravels, interbedded with silts and clays (Figure 8). A brief and final advance of the glacier deposited up to 12 m of the sandy silt Halton till on the southern flanks of the moraine (Funk, 1977b; Intera Kenting, 1990). Today the Oak Ridges Moraine, rising 250 m above the till plain to the south, is the predominant physiographic and hydrogeologic feature of this

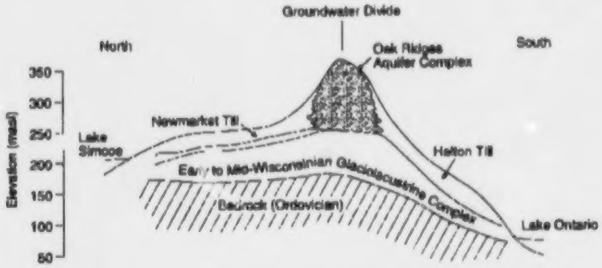

FIGURE 5. Cross-sectional sketch of Oak Ridges Moraine. (Gerber, 1992)

Reference: Gerber, R., Personal Communication, Groundwater Research Group, Scarborough College, University of Toronto, July 8, 1992

Figure 8: Cross sectional sketch of Oak Ridges Moraine (from Gerber, 1992)

region. It is a major recharge area, a headwater area for major streams and rivers, and a surface water divide between the drainage basins of Lake Simcoe and Lake Ontario

The base of the moraine is defined by a thick layer of till (Turner, 1977b). Beneath the till are bedrock valleys that contain up to 140 m of fine-grained sediments, principally of glaciolacustrine origin (Eyles et al., 1985). The largest of these bedrock valleys is the broad, north-south trending Laurentian channel, located at the western end of the moraine (Intera Kenting, 1990).

The rolling and hummocky topography of the moraine's surface and the irregular geometry of the sand and gravel lenses give rise to a highly complex system of aquifers. Based on the occurrence and distribution of coarse-grained materials, two separate aquifer systems can be differentiated. They are separated at depth by the thick till that defines the base of the moraine (Intera Kenting, 1990). The areal extent of both aquifer systems coincides with the outline of the moraine (Sibul et al., 1977). The shallow system is found to a depth of 76 m and contains both confined and unconfined aquifers.

Transmissivities of the shallow aquifer system range from 10^{-5} to 10^{-2} m^2/s with yields of 0.5 to 5 L/s which are suitable for domestic and stock requirements. Wells capable of producing up to 53 L/s for municipal and industrial purposes are also known. Many of these wells are developed along the southern flanks of the moraine where the aquifer is confined by the Halton till and artesian conditions are found (Intera Kenting, 1990).

The Oak Ridges Moraine is underlain by a thick till of low permeability which causes the bulk of infiltrating water to move laterally (Turner, 1977b; Singer, 1981). The groundwater that does not move laterally moves down through the till at an estimated rate of 30 mm/a to recharge the deep aquifers found in buried valleys beneath the till. Within the buried Laurentian channel, deep aquifers are sources of municipal supplies for Newmarket, Aurora and Oak Ridges. Occurring at depths of 88 to 125 m below surface, these aquifers have a limited lateral extent as indicated by the results of pumping tests. These tests clearly indicate impermeable boundaries.

Transmissivity of the deep aquifers is about 10^{-2} m^2/s and storativity ranges from 10^{-6} to 10^{-4}. It has been suggested that each square kilometre of these deeper aquifers is capable of sustaining a yield of 0.9 L/s (Intera Kenting, 1990).

Along the ridge of the moraine there is little or no overland flow since rain and snowmelt readily infiltrate the sands and gravels exposed at surface (Singer, 1981; Intera Kenting, 1990). The texture of the tills varies from sandy loam to silty clay, resulting in locally variable permeabilities and infiltration rates. Detailed mapping of the Musselman Lake area has indicated the existence of "windows" of high permeability in the Halton till (Intera Kenting, 1990). The regional water table is found at depths up to 35 m (Turner, 1977b); however, water is frequently found at much shallower depths due to perching of water by fine silt and clay aquitards (Intera Kenting, 1990).

Groundwater resources of the moraine are not fully used; much of the groundwater discharges in the form of seepages and springs along the sharp topographic break of the south slope and along incised stream valleys (Funk, 1977b). A major discharge zone from the moraine is located northwest of Stouffville in the Rouge River basin. The constant discharge of groundwater maintains wetlands and provides baseflows to streams flowing to Lake Ontario and to Lake Simcoe. The low temperature of the discharging groundwater provides a habitat in local streams for important cold water fish species such as brook trout and brown trout (Meisner, 1990).

Throughout much of the moraine, the quality of the water is generally good to excellent except where the water contains undesirable quantities of iron. The water is hard and predominantly a calcium bicarbonate type (Sibul et al., 1977).

Lake Ontario Shore - South of the Oak Ridges Moraine

The Oak Ridges aquifer system and thirteen other aquifer systems have been identified in the Duffins Creek-Rouge River drainage basins located south of the moraine. The aquifer systems were identified on the basis of similarity of geologic materials, depositional environment, and similar elevations of the top of each aquifer (Sibul et al., 1977). They range in thickness from 3 to 9 m and in areal extent from 10 to 57 km^2, with yields in the range of 1 to 5 L/s. Based on a preliminary correlation with the stratigraphy of the Scarborough Bluffs 10 km to the southwest, the aquifers were grouped into upper and lower aquifer systems. Average transmissivities for upper and lower aquifers range from 10^{-4} to 10^{-3} m^2/s, storativities from 10^{-5} to 10^{-4} (Sibul et al., 1977). An interpretation of hydrochemical data from the fourteen aquifer systems suggests that the aquifers are hydraulically connected and are effectively a regional groundwater system, which flows south to Lake Ontario (Howard and Beck, 1986).

These aquifers are not heavily exploited and all streams in the Duffins Creek-Rouge River drainage basins receive significant groundwater discharge.

Discharge rates to the Rouge and Little Rouge drainage basins average 1.7 L/s/km^2. Discharge to Duffins Creek averages 4.5 L/s/km^2 and for the Stouffville discharge area the rate is 3.0 L/s/km^2 (Sibul et al., 1977).

The groundwater is a calcium bicarbonate type and an acceptable quality for domestic use. The water is hard to very hard with an iron content that often exceeds the water quality objective of 0.3 mg/L. Concentrations of nitrate have exceeded guidelines in 5 of 44 wells sampled (Sibul et al., 1977).

Aquifers of the buried granular type have also been identified east and west of the Duffins Creek-Rouge River drainage basins. In these areas sand and gravel aquifers are found in preglacial drainage channels and in outwash and deltaic deposits beneath the Halton till.

East of the Duffins Creek-Rouge River basins, the overburden of the Bowmanville area thickens from 6 m along Lake Ontario to 215 m near the Oak Ridges Moraine. Up to 30 m of deltaic sands and 6 m of bedrock channel sands and gravels beneath the Halton till provide important sources of groundwater to the area. The towns of Newcastle and Orono rely exclusively on groundwater, while Bowmanville uses a combined source of groundwater from the Tyrone springs and water from Lake Ontario (Singer, 1981).

The geometric mean of the specific capacities of wells in this area is 10^{-1} L/s/m and hydraulic conductivities range from 10^{-5} to 10^{-4} m/s (Funk, 1977b; Singer, 1981). The surficial material in the northern part of the area tends to be more permeable than in the south resulting in greater recharge in the north. Estimated recharge rates in the north range from 220 to 280 mm/a while in the south average recharge is 75 mm/a (Funk, 1977b).

Analyses of groundwater chemistry show the water to be acceptable quality for municipal, domestic and agricultural uses. There is a general increase in total dissolved solids as the groundwater flows from north to south (Funk, 1977b).

West of the Duffins Creek-Rouge River basins, buried granular aquifers are found in the Laurentian channel, a broad bedrock depression that underlies Toronto. The granular deposits are exposed in the Scarborough Bluffs which rise 90 m above Lake Ontario. At Scarborough Bluffs the deltaic Scarborough Formation is 60 m thick and lies near the base of the Laurentian channel (Figure 9). The Scarborough Formation, and lying conformably above it, the Sunnybrook till, have been traced as far north as Barrie where the Scarborough Formation has thinned to 25 m. The sands of the Scarborough Formation form a major aquifer within the Laurentian channel, providing a regional flow system connecting Georgian Bay and Lake Ontario (Eyles et al., 1985).

The Seminary and Meadowcliffe tills alternate with deltaic sands of the Thorncliffe Formation and overlie the Sunnybrook till. The Thorncliffe Formation has been identified as a buried granular aquifer as far east as the Bowmanville area (Sibul et al., 1977; Singer, 1981).

In the area between Toronto and the Niagara Escarpment a number of buried granular aquifers have been identified. One of the most productive aquifers is the Brampton esker. The sands and gravels of the esker once yielded more than 7.6 L/s of good quality water for the city of Brampton. Brampton now obtains its water from a regional supply system with Lake Ontario as its source (Gartner Lee and Associates, 1984).

Extending along the base of the Niagara Escarpment west of Toronto, an outwash sand and gravel deposit forms another major aquifer for this part of Ontario. This aquifer, known as the Georgetown aquifer, is unconfined where the sand and gravel is exposed near the Escarpment and confined in the eastern portion by till. Water is found at depths of 7 to 50 m below the surface and static water levels rise to surface in some areas. The aquifer has a potential yield greater than 7.6 L/s and provides a municipal supply for Georgetown (Gartner Lee and Associates, 1984). Hydraulic conductivity of the aquifer ranges from 10^{-4} to 10^{-3} m/s (Funk, 1979).

Simcoe Area - North of the Oak Ridges Moraine

Where the Laurentian channel underlies the Oak Ridges Moraine, the combined thickness of sediments totals 250 m, the greatest accumulation of Quaternary sediments in Ontario. Due to the lack of data from deep wells penetrating the entire section in this area, stratigraphic boundaries and connections between sediments in the Laurentian channel north and south of the moraine are not well known.

From north of the moraine to Georgian Bay, the Laurentian channel coincides with a system of fine to coarse sand aquifers known as the Alliston aquifer complex. Found at various depths between elevations of 120 and 160 m asl, the aquifers are generally 3 to 6 m thick and are confined by up to 12 m of silts and clays which have been interpreted as the deep-water sediments of a lacustrine environment (Turner, 1977a).

Depending on topography, the static waterlevel can be as deep as 30 m or above ground. Yields range from 0.38 to 53 L/s, depending on

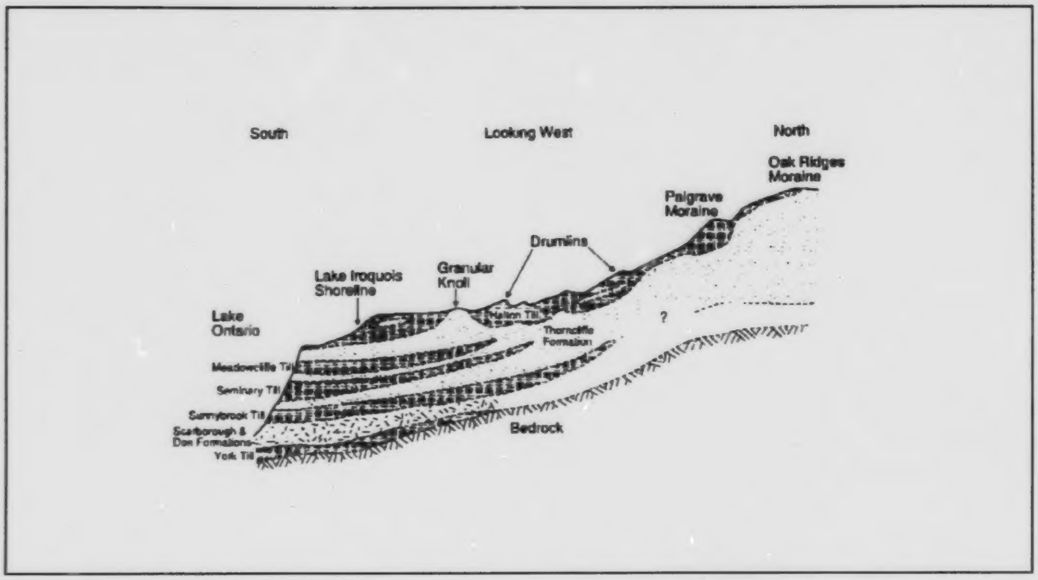

Figure 9: Cross sectional sketch of eastern Metropolitan Toronto (from Gartner Lee and Associates, 1984).

coarseness and thickness of the sand (Sibul and Choo-Ying, 1971). The average transmissivity of the Alliston is about 10^{-3} m^2/s (Vallery et al, 1982).

Direction of groundwater flow is north to Nottawasaga Bay with the exception of a narrow strip along the eastern boundary where flow is east toward Lake Simcoe. Major areas of discharge include the Nottawasaga and Schomberg river valleys, and along the shore of Nottawasaga Bay at Wasaga Beach (Turner, 1977a). This aquifer system provides water to a number of communities in the area west of Lake Simcoe, including the municipal well at Alliston which has a rated capacity of 27 L/s. Other communities that use the Alliston aquifer system as a source of water include Aurora, Newmarket and Innisfil. The more productive aquifers at Barrie and Bradford occur at higher elevations and are not considered to be part of the Alliston complex. Aquifers at similar elevations to those of the Alliston complex are found in the Laurentian channel south of the Oak Ridges Moraine. However, due to the lack of well data, the hydraulic relationship of these aquifers to the Alliston aquifer system is not known (Vallery et al., 1982; Turner, 1977a).

Other less extensive buried granular aquifers are found north of the moraine. The Holland and Black River drainage basin is located south of Lake Simcoe and along the eastern edge of the Laurentian channel. Two buried granular aquifer systems, the Schomberg and the Hope, are found between elevations of 207 and 247 m asl, approximately 80 m above the Alliston aquifer system. In the western part of the drainage basin near the Holland River, the Schomberg aquifer consists of lenticular deposits of fine to medium sand and minor gravel (Vallery et al, 1982; Gartner Lee and Associates, 1984). The Schomberg has a probable yield of 1.5 L/s. In the eastern part, the Holt aquifer consists of sand and gravel with an expected yield of 2.3 L/s, and an average depth to the static water level of 12 m. Average transmissivities for the Schomberg and Holt aquifers are about 10^{-4} m^2/s (Vallery et al., 1982).

Most of the groundwater from the aquifers of this area is a calcium bicarbonate type. Although the water is hard and mineralized with a high content of total dissolved solids and iron, it is generally suitable for domestic and irrigation uses (Sibul and Choo-Ying, 1971; Vallery et al., 1982).

Glacial Till of South Central Area

A hydrostratigraphic unit that plays an important role in the hydrogeology of the South Central Area is the Halton till. It is found at or near the surface from Niagara to Port Hope and is the most widespread glacial deposit in the area. Representing the last advance of the Wisconsinan glacier, the Halton is a silty to clay till with interbedded sand and gravel deposits. The thickness of the Halton till ranges from 3 to 12 m with local thinnings and thickenings of 1 m and 30 m respectively. The Halton till is heterogeneous with correspondingly variable hydraulic properties. The texture of the till becomes coarser eastward and a corresponding increase in hydraulic conductivity is likely (Gartner Lee and Associates, 1984).

In the Duffins Creek drainage basin significant vertical recharge passes through the till (Howard and Beck, 1986). In other areas it exhibits a low hydraulic conductivity and can act as a confining layer. In such cases an active flow system near the surface of the till has been observed. Weathering has caused the upper 2 to 3 m to be fractured and in some places fractures have been observed to a depth of 9 m. The flow of water through these fractures is the dominant method of groundwater movement within the shallow upper zone of the till (Gartner Lee and Associates, 1984).

Although of low hydraulic conductivity compared to the buried granular aquifers, deposits of till or glaciolacustrine clays and silts can provide wells capable of supplying adequate yields for domestic purposes. Transmissivities rarely exceed 10^{-5} m^2/s and yields are controlled by the storage capacity of the well (Ostry, 1979b; Funk, 1977b).

Surficial Deposits of South Central Area

During the recession of the Wisconsinan glacier from the Lake Ontario basin, the ice front retreating to the north and east acted as a dam and caused the accumulation of meltwaters. Confined by the ice front to the east and the highlands to the west, the meltwaters formed a high level lake, Lake Iroquois, with a shore 3 to 13 km inland from the present shore of Lake Ontario (Chapman and Putnam, 1984).

A significant part of the north shore of Lake Ontario is covered by a thin veneer of surficial sands and gravels of Lake Iroquois shoreline deposits. Locally developed for domestic water supply, the water quality is generally adequate, but the aquifers are relatively thin and yields are susceptible to seasonal water level fluctuations and contamination from road salt and pesticides (Wang, 1986b; Funk, 1977b; Gartner Lee and Associates, 1984).

North of the Oak Ridges Moraine and just east of the Niagara Escarpment, the land has a hummocky topography typical of kames and kame terraces. The unconfined sand and gravel aquifers formed by the kames vary in thickness to over 30 m with a water table that is 15 m below the surface on average. Although yields are highly variable and dependent on sufficient thickness of saturated material, yields are generally adequate for domestic supplies. Average transmissivity is 10^{-4} m^2/s (Sibul and Choo-Ying, 1971; Vallery et al., 1982).

East of the kame hills and within the drainage basins of the Nottawasaga and Boyne Rivers, a plain of fine to medium sand was deposited by glacial Lake Algonquin. The sand deposits form an unconfined aquifer known as the Lake Algonquin sand aquifer which is an important local source of domestic water. Less than 3 m thick along the margins of the plain, the sand thickens to over 15 m in the river valleys. The water table is usually found 3 to 6 m below surface, except in areas adjacent to the rivers where depth to the water table increases to 12 m. The saturated zone is about 9 to 11 m thick. Average transmissivity is about 10^{-4} m^2/s and yields will vary between 0.23 and 0.80 L/s (Sibul and Choo-Ying, 1971; Vallery et al., 1982; Hill, 1982).

Most of the groundwater is a calcium bicarbonate type and is generally very hard and highly mineralized. Although the total dissolved solids and iron content of water samples frequently exceed drinking water objectives, the quality can be easily improved by domestic water treatment systems (Vallery et al., 1982).

1.5 Hydrogeology of the Ottawa-St. Lawrence Lowlands

These lowlands are separated from the Great Lakes Lowlands by the Precambrian Frontenac Arch. They extend from the Ottawa and St.Lawrence valleys into Quebec, and are bounded to the west by the Frontenac Arch and to the north by the Canadian Shield (Figure 1). Clastic sedimentary rocks and carbonates of Cambrian and Ordovician age underlie the overburden. A distinguishing feature of this region is the extensive modification of the overburden by the postglacial incursion of the Champlain Sea which blanketed the area with a layer of marine clay. On top of the clay are extensive surficial sands, deposited as a delta by the ancient Ottawa River.

1.5.1 Bedrock

The Ottawa Valley, an important feature of the area, is a graben with steeply dipping faults that trend east-southeast. Most of the bedrock is either flat lying or gently undulating except near principal fault zones where fault blocks may be tilted. The faulting has placed younger rocks in abrupt contact with older rocks, and in places, permeable rocks next to less permeable rocks. The faults may also act as groundwater barriers if they have been sealed by fillings of calcite (Brown, 1967). The faults exert a strong influence on groundwater flow and well productivity (Farvolden and Cherry, 1988).

The oldest Paleozoic formation in the area is the grey and yellow sandstone and siltstone of the Nepean Formation. The Nepean Formation appears in patches along the boundary with the Frontenac Arch at the western end of the area. Ranging up to 85 m in thickness, the best aquifers in the formation are found in its upper and lower members. Vertical and horizontal joints are well developed and transmissivities range from 10^{-6} to 10^{-4} m^2/s. Average yields are about 0.8 L/s, satisfactory for domestic requirements. Much higher yields from 15 to 50 L/s, capable of meeting the requirements of a small municipality, are provided by sections where there are substantial thicknesses of well developed fractures. However, in such cases serious interference problems can occur as a result of a limited recharge area and boundary conditions imposed by local faulting and facies changes (Jeffs and Hore, 1972). High concentrations of total dissolved solids can also impair water quality (Brown, 1967; Chin et al., 1980).

About 80 % of the bedrock aquifers are formed by the carbonates of the Oxford and Ottawa Formations (Chin et al., 1980). These Ordovician formations are composed of limestones and dolomites with minor shale and sandstone. Each of the formations may contain several aquifer zones depending on the rock type and distribution of fractures. For example, the Ottawa Formation shows variations in hydraulic conductivity from 10^{-7} to 10^{-5} m/s (Gartner Lee and Associates, 1982). In the Ottawa area, the Ottawa Formation is massive and transmits very little water. Yet in the eastern and northern portions of the Ottawa-St. Lawrence area, it has been developed as the main regional aquifer, capable of yielding 0.4 to 1.1 L/s (Brown, 1967).

The limestones and dolomites of the Oxford Formation are generally capable of supplying fresher water at higher yields than the limestones and shales of the Ottawa Formation (Chin et al., 1980). The Oxford Formation occupies about a third of the Ottawa-St. Lawrence area and is a major source of water for the Smiths Falls-Brockville area. Most of the wells are sited in the Smiths Falls limestone plain where there is very little overburden and the aquifer is unconfined. Average well yields are 0.4 to 1.1 L/s, but high capacity wells up to 32 L/s have been developed (Brown, 1967; Gartner Lee and Associates, 1982).

The Billings and Carlsbad Formations, found southeast of Ottawa, are relatively limited in extent. These formations are composed of shale and yield small quantities of highly mineralized water (Brown, 1967).

1.5.2 Overburden

Buried Granular Deposits

Extensive buried granular aquifers are uncommon in this area. However, buried sand and gravel aquifers have been identified in the northern portion of the South Nation River basin (Chin et al., 1980) and provide adequate quantities of water for domestic, and locally small municipal supplies. Confined by 10 to 40 m of clay, the aquifers are up to 50 m thick and are often found overlying bedrock (Gartner Lee and Associates, 1982). Depth to the static water level ranges from 3 to 15 m below surface and average transmissivity of the aquifers is about 10^{-4} m^2/s. Most of the groundwater is a calcium bicarbonate type with high concentrations of total dissolved solids and iron (Chin et al., 1980).

South of Ottawa, near the airport in Gloucester, a 25 m thick glacial outwash deposit overlies the bedrock and is confined by a thin layer of silt. The outwash aquifer consists of a sequence of silts, sand, gravel and boulders and is hydraulically connected to the bedrock in places. The porosity is about 30 to 35 % and the mean hydraulic conductivity is 10^{-4} m/s (Jackson et al., 1985).

Marine Clay and Glacial Till

In much of the central and eastern portions of the area, glacial till deposited directly on bedrock is overlain by marine clay of the Champlain Sea. Total combined thickness of the till and clay varies from 0 to 30 m, but is usually around 16 m. Both the clay and the till have highly variable thicknesses that range from less than 2 m to more than 20 m. The hydraulic conductivity of the clay is so low at 10^{-10} m/s, that pore waters of the deeper clays date back to the time of deposition 10,000 years ago (Gartner Lee and Associates, 1982). The low permeability of the clay and till provides a confining layer to the Ottawa Formation which is usually the bedrock aquifer in this area (Gartner Lee and Associates, 1982).

Surficial Granular Deposits

The sand of an ancient delta of the Ottawa River lies in a continuous belt stretching 100 km from south of Ottawa to Hawkesbury. The sand plain, known as the Russell and Prescott sand plain, is 3 to 9 m thick and covers a total area of 1,550 km^2 (Chapman and Putnam, 1984). The texture of the deposit is variable, ranging from fine-to-coarse sand to sand and gravel. The hydraulic conductivity varies with texture, being 10^{-4} m/s for the sand and gravel and 10^{-6} m/s for the fine sand. The aquifer is extensively used for domestic water supplies (Woelfe, 1983; Gartner Lee and Associates, 1982).

1.6 Hydrogeology of the Canadian Shield

The largest of Ontario's major physiographic and hydrogeologic regions, the Canadian Shield is bounded to the south by the Great Lakes Lowlands and to the north by Hudson Bay and its Lowlands. It continues west into Manitoba and east into Quebec (Figure 1). The Shield consists predominantly of Precambrian granites, gneisses, metasedimentary and metavolcanic rocks. Belts of metasediments and greenstones that trend east-west are interspersed with granitic intrusives and gneisses (Farvolden et al., 1988).

Due to the low hydraulic conductivity ($<10^{-10}$ m/s) of the unfractured rock mass, fractures control both the occurrence and flow of groundwater in the bedrock. The availability of groundwater is controlled on regional scales by large discontinuities such as faults, lineaments, dykes and intensely weathered zones. Local flow systems are controlled by the interconnection of fracture zones developed as sheeting structures and vertical fractures.

The most detailed studies of the hydrogeology of the Canadian Shield were conducted as part of the Canadian Nuclear Waste Management Program. This research focused on shallow, intermediate and deep flow regimes.

1.6.1 Bedrock

The shallow regime, extending to a depth of 150 m, consists of local freshwater fracture flow systems that behave much like porous media environments. Although groundwater is transmitted via fractures, the water table is a subdued replica of the topography and pumping produces drawdowns similar in size and geometry to that of a porous medium. In places, the overburden and bedrock groundwater systems may be hydraulically connected (Farvolden et al., 1988). Unlike a porous medium, however, a successful well that has intersected a fracture transmitting groundwater may be located next to an unsuccessful well that missed the fracture. Groundwater occurrence is unpredictable and well yields are variable. Yields in excess of 16 L/s have been reported from wells in Precambrian rocks in the Moira River area of southeastern Ontario at Deloro, Madoc and Tweed. In this area, 40 % of the domestic wells have yields less than 0.15 L/s and 5 % have failed to yield supplies capable of meeting domestic requirements (Sibul et al., 1974). Most of the wells obtain water within 15 m of the surface (Wang and Chin, 1978). The hydraulic conductivity of fracture zones can range from 10^{-7} to 10^{-3} m/s depending on the size and distribution of fractures (Ostry and Singer, 1981).

The hydrogeological properties of a block of fractured monzonitic gneiss measuring 200 m by 150 m by 50 m depth were studied at a site near Chalk River (Raven, 1986). The results indicate that large structural features such as fracture zones, faults and dykes play an important role in controlling shallow flow systems in fractured rock. Fracture zones and faults act as primary groundwater flow pathways, while dykes act as impermeable boundaries. The presence of vertical fractures, often undetected using vertical boreholes, may play an important role in controlling flow within the shallow regime. Raven (1986) conducted over 1,400 hydraulic tests in 17 boreholes and interpreted the results using a fracture-orientation-aperture model. Results of the modelling suggested that shallow local flow systems in crystalline rock may be studied using methods more commonly employed for porous media, provided that the large scale structural features (fracture zones and dykes) are explicitly incorporated.

The shallow groundwater is generally low in dissolved solids, neutral to slightly acidic and coloured but not turbid (Farvolden et al., 1988).

The intermediate regime has been identified at depths of 150 to 600 m, far too deep to be exploited for supplies of water. At these depths the water is brackish, having an increased concentration of minerals due to water reacting with fracture fillings and fracture walls. This regime is a transition zone between the fresh water of the shallow regime and the brine of the deep regime.

Hydrogeological studies at East Bull Lake north of Sudbury, focused on the measurements of the hydraulic and chemical properties of a gabbro-anorthosite pluton to depths of 800 m (Raven et al., 1987). The results of this investigation revealed that hydraulic conductivity of the rock mass decreases with depth from an average of 10^{-8} m/s near the surface to less than 10^{-12} m/s below the 400 to 500 m depth. Shallow (< 200 m) and deeper regional groundwater flow systems are controlled by several permeable fracture zones. Extensive fracturing is associated with the base of a troctolite horizon, a porphyritic dyke and a regional scale fault (Folson Lake Fault). These fracture zones have average hydraulic conductivities of 0.6 to 3×10^{-7} m/s. Groundwater flow in the upper 200 m of the system reflects local topography. Strong vertical gradients are noted in the 200 to 500 m depth zone. In the 700 to 800 m zone data suggest that water flows up and then horizontally towards the Folson Lake Fault. This study illustrates the control of large scale geological and structural features on local and regional flow systems in Precambrian rocks. Thus, it is surmised that large faults throughout the Canadian Shield act as regional discharge or recharge zones.

The groundwater chemistry in the upper 250 m of the East Bull Lake pluton is controlled by rock-water interactions in the fractures and not by the bulk rock composition. In the shallow zone calcium bicarbonate and sodium bicarbonate waters are found. Isotopic measurements show that these waters are meteoric in origin and similar in isotopic composition to present day precipitation. The deeper sodium bicarbonate waters are isotopically lighter and suggest a glacial meltwater component. Salt water is found at depth (Raven et al., 1987). Because modern-day groundwater is found to depths of 250 m or more in other areas of the Shield (Bottomley et al., 1984), the importance of protecting these aquifers from sources of contamination is imperative.

Below 800 m the waters are calcium-sodium-chloride brines with total dissolved solids exceeding 100,000 mg/L. The origin of these brines is unclear, but may be due to substantial rock-water interaction or to mixing with deep saline waters (Farvolden et al., 1988). The brines are below the active groundwater flow system and could be very old.

In many parts of northern Ontario, water from drilled wells is hard with values frequently exceeding 250 mg/L as $CaCO_3$. In addition, heavy metals are often found in groundwater supplies. Problems with iron and manganese are widespread and the use of iron removing treatment devices is common. In some areas, metals such arsenic, cadmium, nickel, lead, copper and zinc can present problems with concentrations being well above the drinking water objectives (Gehrels, personal communication, 1992)

Several uraniferous rock formations have been identified extending east-west across northern Ontario. Groundwater in these areas may have elevated levels of uranium and/or radionuclides such as radium-226 and radon-222 (Gehrels, personal communication, 1992).

1.6.2 Overburden

Surficial deposits of glacial origin cover approximately 90% of the Canadian Shield. Despite the abundance of surface water on the Shield the granular deposits of the overburden are frequently relied upon for water supplies. Since there are often problems with high bacterial levels in surface water, the overburden can provide groundwater for domestic or municipal consumption that does not require extensive treatment (Gehrels, personal communication, 1992). Overburden aquifers have been extensively exploited in Sudbury, Sault Ste. Marie, Iroquois Falls, Blind River, Hornepayne, Callandar, Raymore, Moonbeam and Fauquier (Richards, personal communication, 1991).

Granular Deposits

The thickness of overburden ranges from 0 to greater than 20 m and averages less than 10 m thick. Where the overburden consists of finer grained deposits such as tills, lacustrine and eolian deposits, groundwater yields of 2 L/s and transmissivities of 10^{-5} to 10^{-4} m^2/s are common (Wang and Chin, 1978). Large eolian and outwash deposits are found northeast of Atikokan, around Ignace and stretching north from Vermilion Bay to Red Lake. Bands of fine sand over bedrock located near Fort Frances act as "quicksand", causing sedimentation of drilled wells (Gehrels, personal communication, 1992).

In other locations the overburden is composed of sand and gravel deposits such as eskers, outwash plains, interlobate and ground moraines and to a lesser extent, kame deposits. These sand and gravel deposits are usually less than 40 m thick and tend to have high water supply potentials with transmissivities of about 10^{-4} to 10^{-3} m^2/s. In the Elliot Lake area, groundwater velocities in a glaciofluvial sand aquifer range up to 440 m/a (Dubrovsky et al., 1984). One municipal well in the Nakina area is reported to have a maximum yield of over 40 L/s and at Kapuskasing and Cochrane, municipal wells in buried sand and gravel aquifers yield more than 16 L/s. In the Marathon area on the north shore of Lake Superior, a large sand and gravel deposit is a productive aquifer (Gehrels, personal communication, 1992)

Clay and Glacial Till

Due to their low hydraulic conductivity and large areal extent, clay deposits form important hydrostratigraphic units on the Shield. The extensive clay deposits of the Cochrane clay belt stretch from Longlac to Cochrane and extend north to James Bay. There are also large clay deposits around New Liskeard.

Other less extensive clay plains exist on the Shield (Gartner Lee and Associates, 1982). The surficial deposits underlying the Pic River and Black River watersheds (northeast of Marathon) and the area between Black Bay and Nipigon Bay (west of

Red Rock) are composed primarily of clay. A clay belt is also found south of Thunder Bay (Gehrels, personal communication, 1992).

Thick lacustrine deposits of varved clay are also common on the Shield. These deposits tend to be limited to localized pockets and bands and are usually found along existing and former rivers and lakes. They extend up to 100 m thick and have extremely low vertical hydraulic conductivities in the range of 10^{-11} to 10^{-8} m/s. A relatively continuous deposit of varved clay extends east and west of Dryden from Dyment to Earl River, north to Lac Seul and south to Rainy Lake on the Canada-United States border (Gehrels, personal communication, 1992).

Tills containing large quantities of clay and having low hydraulic conductivities are found in local areas northeast of Thunder Bay, around Lake of the Woods and near Sioux Lookout. In many areas the till is overlain by thick clay and silt deposited in fluvial and lacustrine environments during the latter stages of the last glaciation (Gehrels, personal communication, 1992).

In general, the quality of groundwater in the overburden is good and is generally low in dissolved solids. However, in some areas it is highly coloured due to high concentrations of dissolved organics such as tannins and phenols. This can produce unpleasant colours and tastes. Dug wells are also susceptible to quality problems such as nitrate and/or bacterial contamination (Gehrels, personal communication, 1992)

1.7 Hydrogeology of the Hudson Bay Lowlands

Located in the northeastern part of Ontario, this region is bounded by the Canadian Shield to the south and west and by Hudson and James Bays to the north and east (Figure 1). It is a sparsely populated area containing only a few villages.

The Hudson Bay Lowlands are a low, poorly drained plain covered with muskeg. Elevations rise gently from near sea level to 120 m asl except for the Sutton Hills inlier which stands 150 m above the surrounding surface. At several places the featureless plain is interrupted by beach ridges. The most prominent single feature is the Great Beach, which is 200 to 800 m wide, and can be traced for about 800 km. The Hudson Bay Lowlands and adjacent Shield support the largest area of organic terrain in the world. Swamp, fen, forested bog and tundra peat have accumulated on the flat, poorly drained glacial lake and marine plains, accumulating up to 4 m of organic sediment (Dredge and Cowan, 1989).

The bedrock consists of Paleozoic rocks divided into 16 formations ranging in age from Ordovician to Devonian. Reaching up to 1,800 m in thickness, the formations consist mainly of carbonate rocks such as limestone, dolomite, sandy limestone and dolomitic limestone. A patch of Cretaceous rocks, consisting of fire clay, micaceous quartz sand and lignite, occurs in the southern portion of the Lowlands.

Limestone and dolomite are the most extensive bedrock types, underlying the majority of the Lowlands area. Areas with these types of bedrock have the greatest potential for high-capacity wells. The mean transmissivity of the limestone and dolomite is about 10^{-4} m^2/s and individual wells may yield up to 16 L/s. Other types of bedrock include Ordovician sandstone and Silurian sandstone and siltstone. Only limited data exist for these types, but it has been estimated that wells in these bedrock units may yield around 1.9 L/s. Information on the Upper Devonian carbonaceous shale does not exist (Wang and Chin, 1978).

In contrast to the Canadian Shield, the till of the Hudson Bay Lowlands is almost continuous and is considerably thicker. Broad preglacial valleys have been infilled with more than 60 m of till, and a thickness of 145 m has been recorded. In the Lowlands as many as seven separate till sheets have been recognized.

The predominant constituent of the overburden is marine clay, deposited when the Tyrrell Sea invaded the area after the last glacial period. Deposits up to 30 m thick are found where major rivers flowed into the sea. The lowermost facies is stony mud with abundant broken shells. In the James Bay area, lacustrine deposits are separated from overlying marine units by a coarse horizon composed of boulders, pebble gravel and rip-up blocks of clay. The low permeable clay forms an aquitard confining the bedrock aquifers (Dredge and Cowan, 1989).

PART 2 GROUNDWATER QUALITY CONCERNS

2.0 Introduction

In Ontario, groundwater is used by 23 % of the population, with about 1,320,000 people on municipal systems and 1,300,000 people on private residential wells (Hess, 1986; Walker and Partners, 1987). About 190 or 47% of Ontario municipalities use groundwater for all or part of their municipal supply. Some of the larger municipalities that use groundwater include Kitchener-Waterloo, Cambridge, and Sault Ste. Marie (see Appendix A).

On the basis of vulnerability of groundwater to contamination, Ontario may be divided into two major regions: the Canadian Shield and the Great Lakes and Ottawa-St. Lawrence Lowlands. Although aquifers in the Shield are generally more vulnerable than in the Lowlands of southern Ontario, there are fewer potential sources of contamination and fewer demands on groundwater in the Shield area (Ontario Ministry of Natural Resources, 1984). The Lowlands of southern Ontario covering about 17% of the province is, together with its corresponding part in Quebec, the most populated (over 50% of Canadian population), industrialized (75% of Canadian industry) and intensively cultivated (40% of Canadian agricultural productivity) region of Canada (Statistics Canada, 1986; Environment Canada et al., 1987). Threats of groundwater contamination occur frequently and can be quite serious. In fact, municipalities such as Elmira, Smithville and Manotick have switched from groundwater to surface water over the last five to ten years due to contamination of their groundwater supply (Ontario Ministry of Natural Resources, 1984).

Throughout Ontario the most frequent cause of contaminated well water may be due to the improper construction of wells and septic systems. Road salt is a frequent source of contamination in the south, but in recent years has been increasing in northern Ontario. In areas of intensive agricultural production on permeable soils, extensive contamination by nitrates is present (Singer, 1988) and concerns exist about the effects of agrochemicals (fertilizers and pesticides). Although less frequent, contamination from leaky gasoline or heating oil storage tanks and from industrial leaks or spills is potentially more serious. Extensive contamination from industrial leaks and spills and from improper storage in waste disposal sites has been reported (Beak, 1986). Ontario has a comprehensive program for the evaluation and selection of new landfill sites but some of the older sites have caused problems. Groundwater and surface water have also been contaminated by old closed coal gasification sites. Deep-well disposal in relatively shallow formations (about 250 m) has presented problems in the past but is now closely controlled.

Other concerns relate to mine tailings and the proper storage and disposal of radioactive waste. Groundwater mining, primarily a problem of groundwater quantity rather than one of quality, is becoming a serious concern both in southern (because of intense residential development) and northern Ontario (because of development of often very limited supplies).

A number of sources of groundwater contamination are discussed in the following sections. Groundwater may also provide a major pathway for toxins entering the lower Great Lakes and the St. Lawrence River. Because of the importance of the Great Lakes to the province their contamination via groundwater is treated separately in the following detailed discussion of groundwater concerns.

2.1 Contamination of the Great Lakes Waters Via Groundwater

2.1.1 Background

The potential for contamination of the Great Lakes from groundwater has been discussed in some detail (Great Lakes Science Advisory Board, 1985b; Great Lakes Science Advisory Board, 1985c; Beck, 1988). It is recognized that groundwater is "a potentially significant route of transport" (Great Lakes Science Advisory Board, 1985c). However, adequate information has not been available to provide estimates of contaminant loadings or even, in many cases, to unequivocally identify areas where contamination of the Great Lakes via groundwater is most likely to occur. Adequate information on hydrogeologic regimes, the sources and extent of contamination and the contribution of groundwater to the Lakes (i.e. baseflow to tributaries or direct discharge to the Lakes) have not been available.

Groundwater inputs to Lakes Ontario and Erie have been investigated by obtaining cores from lake bottom sediments and extracting the interstitial pore water. Chemical analyses of the pore water and physical properties of the core indicate that shallow and deep regional groundwaters do discharge to the lakes (Frape et al., 1991; Drimmie et al., 1992). Although elevated hydrocarbon levels and/or trace metals are present in the pore water, uncertainty exists about their source. Data suggest that the pore water reflects the chemistry of the underlying rock (Bowins et al., 1992; Drimmie et al., 1992): that is, the interstitial pores contain deep formation waters which have naturally elevated concentrations of hydrocarbons and heavy metals. Further research is required to determine the source of the contaminants.

A rough approximation of groundwater discharge to the Great Lakes has been made. It has been estimated that half of the water entering the Great Lakes is from the atmosphere and the other half is the contribution from tributaries and groundwater discharges. Direct groundwater discharge to the Lakes has been estimated at 9% of the total inflow and indirect discharge through tributaries has been estimated at 15% to 23% of total inflow. Adding the direct and indirect discharges gives a range for groundwater inflow to the Great Lakes of about 24% to 32% of total inflow (Speaker's Commission on the Great Lakes, 1992).

In its recommendations to the Science Advisory Board of the International Joint Commission, the Groundwater Contamination Task Force (Great Lakes Science Advisory Board, 1985c) recommended that information on the hydrogeologic regimes, on land use and on potential sources be collected (primarily from available information), synthesized and presented on interpretive maps. The principal purpose of the maps was to identify areas with the greatest potential for contamination. The recommendations were subsequently endorsed by the Board (Great Lakes Science Advisory Board, 1985a), and some progress has since been made, mostly on the U.S. side (Great Lakes Science Advisory Board, 1987).

The discussion of groundwater and the Great Lakes in this subsection is restricted to situations which may directly affect Great Lakes waters rather than situations that threaten any groundwater in the Great Lakes basin. Information regarding the latter may be found in other parts of this section on groundwater quality.

The main sources of potential groundwater contamination of the Great Lakes are waste disposal sites along the connecting channels and agricultural lands where large amounts of fertilizers and pesticides are being applied.

2.1.2 Connecting Channels of the Great Lakes

The prime areas of concern are along the Niagara River and, to a lesser extent, the St. Clair, Detroit and St. Mary's Rivers (Figure 10). A large number of steel-producing, chemical, petrochemical and other industries have established themselves along these channels. Since the early part of this century, large amounts of chemical waste have been disposed of and have, in some cases, led to major problems (Environment Canada et al., 1987).

The Niagara River Toxics Committee (1984) reported 215 landfill sites on the U.S. side (New York) of the Niagara River and 17 landfill sites were identified in the Niagara and Welland basins in Ontario. Sixty-four U.S. sites and 5 Canadian sites were found to have significant potential to contaminate the Niagara River. Thirteen of the U.S. sites and the Atlas Steel landfill in Welland River basin were judged to definitely contribute or to have contributed contaminants to the river (Koszalka et al., 1985; Niagara River Toxics Committee, 1984).

In the Upper Great Lakes Connecting Channel Study (UGLCCS) waste sites on both sides (within 19 km) of the upper Great Lakes connecting channels (St. Mary's River, St. Clair River, Lake St. Clair, Detroit River) were identified and ranked according to their potential to contaminate the connecting channels (UGLCCS, 1988a). On the U.S. (Michigan) side, 214 sites were identified and sites in areas of groundwater discharge to the channels or tributaries were ranked. The 37 highest ranking sites are listed and described in the UGLCCS (1988b) report.

On the Canadian side, 100 sites were identified and evaluated; 27 sites were ranked in a priority scheme (5 as priority one, 14 as priority two and 8 as priority three). All priority one sites are being further assessed (UGLCCS, 1988b; GTC, 1985). Except for 3 sites in the Sarnia area, sites of most interest for groundwater (if not necessarily for impact on the Great Lakes waters) may be the Algoma disposal site at Sault Ste. Marie and Fighting Island in the Detroit River.

2.1.2.1 Niagara River

In a study on the contributions to the Niagara River from landfills on the American side (Gradient Corporation and Geo-Trans Corporation, 1988), total potential loading from all sites was given as 315 kg/day, with actual loading to the river estimated as 217 kg/day (70 % of the total). Included in the calculations for the loadings were sewer outfalls and groundwater seepage. Groundwater loadings may be compared to the total surface loading from point sources, which was estimated as 1,407 kg/day (Niagara River Toxics Committee, 1984).

In 1991, the Ministry of the Environment released a report on the potential contaminant loadings from the five sites in Ontario. Total potential contaminant loading to the Niagara River

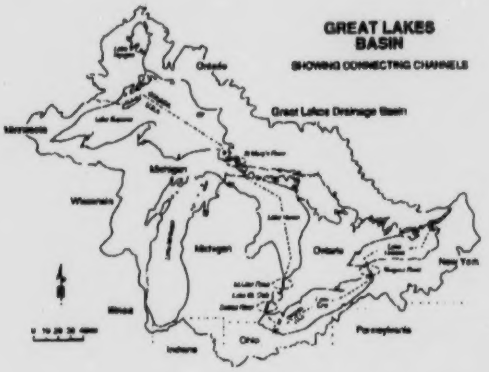

Figure 10: Upper connecting channels of the Great Lakes Basin (from UGLCCS, 1988)

from the sites was estimated to be 30.5 kg/day. The primary contributor, at 26.9 kg/day, was the Cyanamid Inc. plant site in Niagara Falls. The CN Rail landfill in Niagara Falls contributed 2 kg/day of heavy metals and the remainder of the loading was contributed by the landfills at Atlas Steel, the Bridge St. landfill in Fort Erie and the Cyanamid Inc. landfill in Welland (Ontario Ministry of the Environment, 1991).

Along the Niagara gorge, whenever contaminants intercept less permeable formations during their downward movement, they seep out horizontally through the face of the gorge and discharge into the river. The complex regional groundwater flow system in the area is being studied on both sides of the river to better understand contaminant movement (Novakowski and Lapcevic, 1988; Noll and Siegel, 1988; Tepper, 1989; Kappel, 1989; Yager, 1988).

As decided in the Niagara River Toxics Management Plan (U.S. Environmental Protection Agency et al., 1986) and the four-party Declaration of Intent (U.S. Environmental Protection Agency et al., 1987), the sites along the Niagara River are now being assessed to best control sources and prevent discharge of contaminants.

2.1.2.2 St. Clair River

In the Upper Great Lakes Connecting Channel Study (UGLCCS, 1988a), 16 waste disposal sites on the Ontario side and 26 sites on the U.S. side were identified within 19 km of the St. Clair River. Three sites in Ontario have been ranked as high priority and are being assessed for remediation.

There are a number of petrochemical plants and refineries along the St. Clair River, particularly near Sarnia. A 1985 report lists 12 such plants within 10 km of the Sarnia core, many of them adjacent to the St. Clair River (Environment Canada and Ontario Ministry of the Environment, 1985). Most of these industries discharge effluents directly into the river and operate shallow waste disposal sites. From time to time, spills of chemicals occur like the Dow Chemical perchloroethylene spill in 1985 (Environment Canada and Ontario Ministry of the Environment, 1986).

Between 1958 and 1975 deep-well disposal of industrial waste was practiced in the region. The liquid waste was injected into the dolomite of the Lucas Formation (of the Detroit River Group) which is situated between 180 and 275 m in depth (Underground Resource Management, 1984). Approximately 6.4 to 8.0 million m^3 of liquid industrial wastes were disposed of during this 17-year period. Deep-well disposal has resulted in localized phenol contamination in the freshwater aquifer, an important aquifer in the region (UGLCCS, 1988b; Lesage et al., 1991).

In general, transport of contaminants via groundwater to the St. Clair River may be limited because of the thick (up to 40 m) clay layer at the surface and the discontinuity of the underlying "freshwater" sand and gravel aquifer (UGLCCS, 1988b). However, concerns still exist for the potential migration of landfill leachate and industrial spills within the top fractured layers of clay. Uncertainty also still exists over the migration of waste from deep-well injection. That uncertainty is compounded by an unknown number of old, improperly abandoned oil and gas wells in the region (Freeze and Cherry, 1979).

2.1.2.3 St. Mary's River

At the Algoma Steel Corporation site on the St. Mary's River at Sault Ste. Marie, about 700,000 tonnes of solid waste and about 70,000 tonnes of liquid waste per year were disposed, mostly from steel operations. Much of the site is covered by a 3 to 21 m thick layer of slag through which groundwater flows toward the St. Mary's River (UGLCCS, 1988b).

An investigation of the slag disposal site found that groundwater within the site contained high concentrations of PAHs; benzene, toluene and xylenes (BTX); sulphate; cyanide; fluoride; chloride; ammonia; phenols and metals. Due to upward hydraulic gradients the deep groundwater in the bedrock was not contaminated by the shallow groundwater. The contaminated shallow groundwater below the site is not a threat to the water wells that supply Sault Ste. Marie, but does contribute significant loadings to the St. Mary's River. The site contributes 3% of the total chloride load, 15% of the BTX and 32% of the PAHs (Beak Consultants Limited, 1992).

A number of programs have been initiated by Algoma Steel to reduce the loadings to the St. Mary's River. The waste pickle liquor, a major source of chlorides, is being recycled and sent to southern Ontario sewage treatment plants to be used as a phosphorous removal agent. The major source of PAH and BTX loadings was free coal tar which is now being collected and recovered. Monitoring programs for coal tar products as well as for surface and groundwater quality have been implemented (Beak Consultants Limited, 1992).

2.1.2.4 Fighting Island

Fighting Island, on the Canadian side of the Detroit River about 10 km south of Windsor, was used from 1927 to 1980 as a waste disposal site for industrial waste for the BASF Wyandotte Corporation of Detroit. The deposited waste is primarily calcium carbonate and calcium chloride, mixed with other chemicals (GTC, 1985).

In a study by Environment Canada (Environment Canada, 1984b) organic and inorganic contaminants were found (phenols, chlorinated furans, aluminum and other contaminants). Leachates pass through decanting basins before discharging to the river. Shallow groundwater movement occurs radially outwards in the top layers of waste deposits and possibly in the underlying alluvium and clay. Loadings of toxics to the Detroit River from Fighting Island have never been determined but the potential for contaminant loading exists, in view of the short flow path of both surface runoff and groundwater discharge. Monitoring of water quality around the island has never shown any impact on water quality, but this may be due to the high dilution factor in the Detroit River (GTC, 1985).

2.1.3 Agrochemicals

Another potential source of contaminants to the Great Lakes from groundwater is the application of agrochemicals. Eutrophication of the Great Lakes caused by excess nutrients gave rise to the Great Lakes Water Quality Agreement of 1972 (Environment Canada et al., 1987; National Research Council of the United States and Royal Society of Canada, 1985). At that time phosphorus was identified as the prime cause of eutrophication. It has been estimated that 60 to 70 % (or 15,000 to 17,000 metric tonnes per year) of the total phosphorus loading to the Great Lakes comes from non-point sources, mostly via tributaries (Great Lakes Water Quality Board, 1989); some of this will have originated from groundwater.

There has also been a substantial increase in the nitrogen (nitrate and nitrite) concentrations in the Great Lakes (Great Lakes Water Quality Board, 1985, 1987); some of this comes from atmospheric deposition (Bennett, 1986; Barica, 1987; Great Lakes Water Quality Board, 1987) but another portion originates from non-point sources of agricultural activity and some of that will have been transported by groundwater.

Pesticides are another class of agrochemicals that can be transported into the Great Lakes via groundwater. Organochlorine pesticides (lindane, DDT, etc.) have long been reported in the Lakes and are usually detected after accumulation in sediments or fish (Great Lakes Water Quality Board, 1987). Estimates from mass balance calculations for total

DDT (Strachan and Eisenreich, 1988) indicate that most DDT present in the upper lakes (Superior, Huron, Michigan) is from atmospheric deposition (97, 97, 98 % respectively). In the lower lakes (Erie, Ontario), atmospheric deposition is not predominant (22% for Erie, 32% for Ontario) and inflow from tributaries prevails. One may expect the contribution of pesticides from tributaries to originate as a combination of surface runoff and groundwater discharge.

Most of the organochlorine pesticides mentioned above are residuals from past applications. During the 1980's the eight most commonly used pesticides in Ontario were atrazine, alachlor (banned in 1985), metolachlor, cyanazine, butylate, 1,3-D (DCP), metribuzin and 2,4-D (McGee, 1984; Shelton et al., 1988b). Pesticide loadings from groundwater have been estimated to be 18% of total loading from 11 agricultural watersheds in southern Ontario (Frank et al., 1982).

Atrazine and some of the other eight pesticides have been found in the Thames, Grand, and Saugeen Rivers (Frank and Logan, 1988). Total loading of atrazine from these three major tributaries (the three watersheds account for 36% of all pesticide use in the Great Lakes basin) was 12.3 tonnes in 1985. As most pesticides move slowly in groundwater, groundwater transport (as opposed to surface runoff) may be a significant route only for the more persistent and more soluble ones (e.g. atrazine). Shelton et al., (1988b) have recently evaluated the potential for the transfer of pesticides to surface water in the Great Lakes Region, where they considered application rate as well as the properties of soil.

2.2 Landfill Sites

2.2.1 Existing Landfill Sites

Ontario has conducted an extensive program for the identification and evaluation of existing waste disposal sites (Ontario Ministry of the Environment 1986b, 1988). Sites are initially classified into "A" (potential impact on human health) and "B" (potential impact on environment) sites. The basis of this classification is an evaluation of site records. Sites with high potential impact are further investigated. A report of assessed sites lists 2,450 closed and 1,395 open (active) waste disposal sites (Ontario Ministry of the Environment, 1988).

An additional 283 waste disposal sites are found on federal lands in Ontario (Environment Canada 1984a, 1988). Six of these sites are classified as priority 1, 28 as priority 2, 191 as priority 3, and 58 were not ranked.

Groundwater monitoring is now required for all waste disposal sites. Before 1971, regulations were much more lenient and some of the older sites have contaminated groundwater and wells. In a study by Beak Consultants (1986), over 30 municipal or industrial waste disposal sites and impoundments of liquid waste are listed that have contaminated groundwater or water wells. Widely known cases have occurred at Elmira, where contaminants from past industrial waste impoundments have contaminated an aquifer previously used for municipal supply; Gloucester, where organic chemicals from federal laboratories have contaminated an aquifer which was used for residential wells; and landfill sites in Kitchener, Tiny Township and Aurora (Beak, 1986). On several of these sites, industrial waste was disposed of together with municipal waste. In several cases aquifers were contaminated which were used for municipal or residential wells; some residential or municipal groundwater supplies had to be replaced by water piped in over longer distances, mostly from surface water supplies (for details see Beak, 1986).

Another threat to groundwater from industrial wastes comes from tar ponds of coal gasification plants that operated between the 1840's and 1950's. Forty-one of these sites were identified, several of which might require cleanup (INTERA, 1987a, 1988; Carleton University, 1987; Ontario Ministry of the Environment, 1988). In many cases these tar ponds, containing residues from the gasification process, were covered up when the plant closed; in some cases they are now in the middle ofexpanded cities and their exact location may not be known. In two cases (Ottawa and Waterloo), these ponds were accidentally breached during construction projects resulting in groundwater and (in Ottawa) surface water contamination. Cleanup costs were several million dollars in each case.

2.2.2 Organic Chemicals in Groundwater at Several Ontario Landfill Sites

Researchers at the University of Waterloo have conducted a study for the Ministry of the Environment and Energy on the occurrence of organic chemicals in groundwater at six landfill sites and one waste disposal facility in southern Ontario. The objectives were to determine which chemicals are contaminating groundwaters, how rapidly these contaminants migrate and how persistent they are in groundwater. The groundwater samples from the landfill sites were analyzed for two classes of organic chemicals that are mobile in the environment and are an environmental concern. The two classes were volatile halocarbons which include common chemicals such as trichloroethylene and carbon tetrachloride, and volatile aromatics which include benzene, toluene, and xylenes (Ontario Ministry of the Environment, 1989).

To be representative of most landfill sites in southern Ontario, the study sites were selected to reflect a variety of hydrogeological conditions. Of the five sites located on overburden, three were on permeable, sand deposits where groundwater velocities approach 5 m/d, one was on less permeable sandy till where the groundwater velocity was about 25 m/a, and one was on thick clayey deposits where contaminants move at the rate of 6 cm/a. Two sites were located on sedimentary bedrock which was extensively fractured (Figure 11)

2.2.2.1 Overburden Sites

North Bay Landfill

In North Bay, a plume of contaminated groundwater emanates from a 32 ha landfill that received both municipal and industrial waste since its beginning in 1962. The plume migrates in a shallow unconfined sand aquifer for 800 m to an area of springs where the groundwater discharges to a small creek which empties into Lake Nipissing.

The contamination in the plume consists of inorganics and organics. The contribution of chloride and dissolved organic carbon (DOC) to Lake Nipissing has been calculated to be many times less than that from other sources. The amount of chloride contributed by road salt could be 50 times greater than that contributed by the landfill. The sewage treatment facility contributes 8 times the amount of DOC (Cherry, 1987).

The problem is the presence of halocarbons and aromatic hydrocarbons from industrial waste which was permitted in municipal landfills until the late 1970's. Although the impact on water quality of Lake Nipissing is minimal, the contaminant plume has rendered the water from the aquifer between the landfill and the springs unsuitable for drinking (Table 1).

Old Borden Landfill

This landfill, which is now abandoned, is located on a shallow unconfined sand aquifer at Canadian Forces Base Camp Borden and was mainly used for the disposal of construction debris. The contaminant plume contained only a few organic chemicals at very low concentrations of less than 5 ug/L (Table 1). The lack of contamination probably reflects the innocuous nature of the material in the landfill.

New Borden Landfill

Operating since 1976, the new landfill for CFB Borden is located on silty sand till, material that is less permeable than the sand of the previous landfill. Extending 200 m from the site, the contaminant plume contains contaminants from both classes of organics (Table 1).

Woolwich Landfill

Operated between the 1960's and 1986 in the Waterloo Region, this landfill is located on sand and gravel deposits. The contaminant plume extends 1000 m from the site and contains high concentrations of organic fatty and aromatic acids which are not an environmental concern. Of more concern are the levels of halocarbons such as chloroform which was found at concentrations of tens of ug/L. Aromatic hydrocarbons and various phenols were found at concentrations of hundreds of ug/L (Table 1).

Tricil Waste Disposal Facility (now Laidlaw Environmental Services Ltd.)

The only site in Ontario which accepts hazardous waste is operated by Laidlaw Environmental Services Ltd. in Sarnia. On the Laidlaw site, liquid hazardous waste is incinerated, and ash and other waste is landfilled at a site embedded in a thick (42 m) clay formation.

The migration of contaminants in the thick clay deposit is very slow at 6 cm/a and is due to molecular diffusion rather than transport by groundwater. In a five year period the most mobile

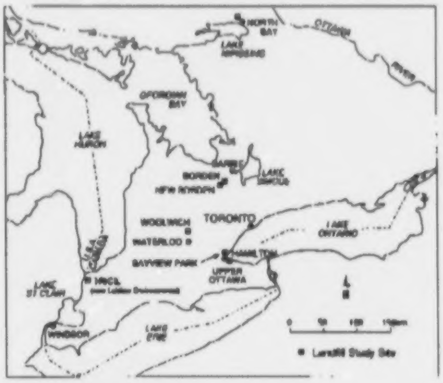

Figure 11: Location of landfill study areas (from Ontario Ministry of the Environment, 1989).

organics such as benzene and toluene have moved less than 30 cm. Although migration of contaminants is slow, they do move even in the absence of groundwater flow (Table 1).

2.2.2.2 Bedrock Sites

Bayview Park Landfill

Located in Burlington near Lake Ontario, the site operated between 1961 and 1974 and received both municipal and industrial waste. The site is underlain by the Queenston Formation shales which are extensively fractured with horizontal bedding plane fractures. The fractures provide the major flow paths for contaminant migration. 1954 to 1978. The complex pattern of groundwater flow in the fractured bedrock made it difficult to define the distribution of the contaminated groundwater. A restricted zone of groundwater contamination was found to extend 100 m from the site (Table 1). However, since the natural groundwaters are poor quality, the contaminants have not caused a major degradation of groundwater quality.

2.2.2.3 Observations from Study

The majority of the organic chemicals found in the groundwater from the landfill sites were various organic acids that are not an environmental concern. However, groundwater from all the sites contained other organic chemicals that are a concern. The similar content of chemicals, despite the differences in hydrogeological conditions, may be due to the similar nature of material disposed of at landfill sites.

Natural processes such as dispersion, biotransformation and retardation have reduced the concentration of the organic chemicals. The concentrations of halocarbons and aromatic hydrocarbons in the groundwater from the landfills are not causing immediate threats to any water supply wells or the quality of surface water.

2.3 Deep-well Injection

Deep-well injection has been used in southwestern Ontario since the early 1900's. Between 1958 and 1975, industrial waste was injected at 16 injection wells, all in Lambton and Kent counties (Underground Resource Management, 1984). It has been estimated that approximately 6.4 to 8.0 million m^3 of liquid waste were injected in relatively shallow formations (180 to 275 m) of the Detroit River Group in the Sarnia area.

These injections have gained some notoriety because upwelling occurred on both sides of the St. Clair River at Sarnia and at Port Huron, Michigan,

Table 1 **Contaminant Concentrations in Groundwaters at Six Landfill Sites (from Cherry, 1987; Ontario Ministry of the Environment, 1989).**

Contaminant	**Landfills**					
	Old Borden	**Woolwich**	**North Bay**	**New Borden**	**Upper Ottawa St**	**Tricil**
Aliphatic, aromatic and carboxylic acids	20	>10000	>300	-	>1000	-
Volatile halocarbons (ug/L)						
Trichloroethane	n.d.	7	<1	90	20	844
Trichloroethylene	n.d.	2	<1	<1	<1	n.d.
Carbon tetrachloride	<1	5	<1	9	p	n.d.
Chloroform	<1	20	<1	25	5	n.d.
Tetrachloroethylene	n.d.	2	<1	<1	<1	n.d.
Aromatic hydrocarbons (ug/L)						
Benzene	3	70	51	50	60	7920
Toluene	1	7500	60	1400	2600	9520
Ethylbenzene	<1	1100	64	120	700	3320
Xylenes	<1	700	140	500	3500	-
1,2,4-Trimethylbenzene	n.d.	10	250	70	450	-
Naphthalene	n.d.	50	15	260	p	2350
Chlorinated benzenes (ug/L)						
Chlorobenzene	n.d.	n.d.	105	n.d.	110	-
Dichlorobenzenes	<1	n.d.	13	n.d.	5	-

p = detected but concentration not estimated, n.d.= not detected, - = not determined a fact which became the reason to end the practice in 1976 (Underground Resource Management, 1984). Since 1976 only brine and produced water may be injected, and this is not permitted within 8 km of the St. Clair River. Concentrated brine is injected into two wells only (operated by Dome in Sarnia). At all other wells, water produced from oil and gas production is injected for disposal and enhanced recovery.

A study of the groundwater quality in the disposal formation and in the freshwater aquifer was conducted by the MOEE and the federal Department of the Environment. Using a monitoring well network it was found that the disposal formation contained significant quantities of phenols, ethyl toluenes and trimethyl benzene. Although the freshwater aquifer, an important source of potable water in the area, was found to contain phenols in one small localized area, widespread contamination of this aquifer was not found (Lesage et al., 1991; INTERA Technologies Ltd., 1992).

In oil production, about 5 barrels of brine is produced for every barrel of oil. The brine is disposed of in wells usually under gravity feed. Deep-well injection of brine is also used to enhance oil recovery after about 40 % of the oil reserves have been depleted and to control the amount of storage in underground salt storage caverns.

All wells for brine disposal are located in southwestern Ontario (Figure 12), with the greatest number in Lambton county which contains 60% of the wells. Kent and Essex counties each contain 13.5% of the wells. The remainder are in Elgin and Haldimand-Norfolk counties and in the Niagara region. Permits and approvals for brine disposal wells are granted by the Ministry of Natural Resources under Regulation 915 of the Petroleum Resources Act.

Of the 51 permitted oilfield brine disposal wells in Ontario in 1991, 36 were active for disposal. Of the 36 active wells, 27 disposed of brine in the Detroit River Group and 6 were injecting into the Bass Islands/Bois Blanc Formations. The volume of injected brines nearly doubled from 773,813 m^3 in 1989 to 1,473,850 m^3 in 1991 (Ontario Ministry of Natural Resources, 1992).

For active wells, individual approvals are required for each well and provisions (casing) have to be taken to prevent contamination of freshwater bodies (e.g. aquifers) or cross contamination of

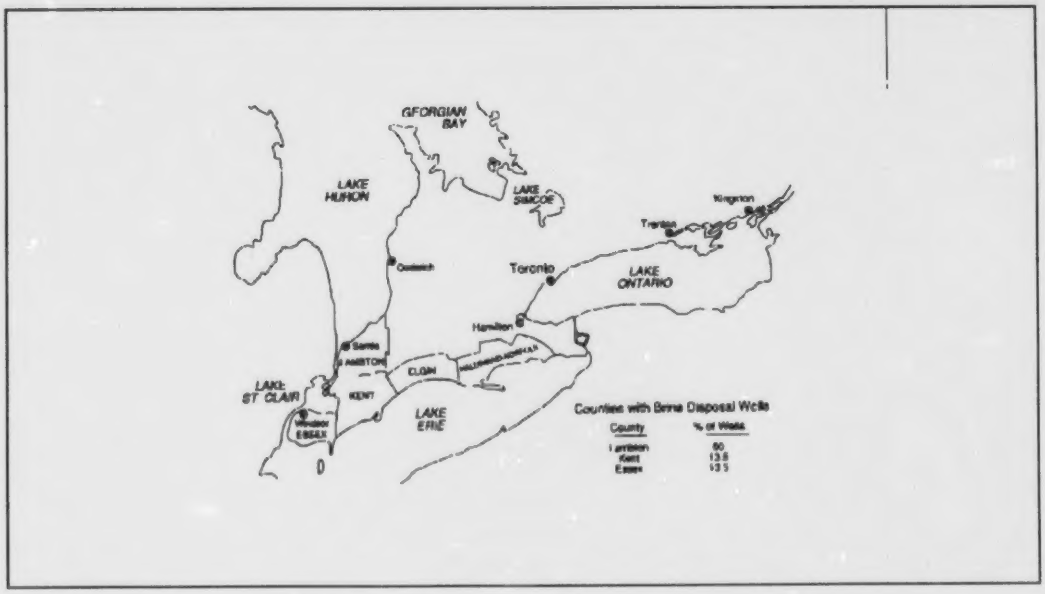

Figure 12: Counties with brine disposal wells (after Ontario Ministry of Natural Resources, 1992).

other formations. All freshwater wells within a 750 m radius of a disposal well must be sampled and analyzed for sodium, chloride, total dissolved solids and phenols (Ontario Ministry of Natural Resources, 1989). As well, operators of injection wells have to keep and submit records on the volumes of injected fluid, its source, injection rates and pressures (see section 3.3.1.4). However, there may be about 30,000 improperly abandoned oil wells in the Sarnia area whose locations are not well known; these, by providing connection between formations, may be the most serious potential threat to groundwater quality. (Van Everdingen and Freeze, 1971).

There are also approximately 60 storage caverns around Sarnia and a few in Windsor that arebeing used for storage by different industries. Brine is kept in surface storage ponds near the caverns. A few caverns are also being exploited for salt recovery (at Windsor, Goderich and Sarnia).

2.4 Petroleum Storage Tanks

Petroleum contamination of groundwater is often the result of small leaks and spills that occur over many years at filling stations and bulk transfer stations. Most leaks occur because unprotected steel tanks or piping corrode over time or because of structural failures during installation. Unprotected steel tanks are thought to have a life span of 15 to 25 years by which time over 50 % may be leaking (Cherry, 1987). The percentage of leaking tanks is estimated from limited surveys to range from 5 to 35 % of all tanks (Clendening, 1984; Groundwater Monitor, 1986; Environment Canada, 1987).

The number of leaking tanks may now be decreasing as tanks are replaced and new tanks are required to have corrosion protection such as an inner lining or made of cathodically protected steel or fibreglass. At present, detailed data on the number of tanks, the number of unprotected tanks, etc. are not available. It has been estimated that there are approximately 15,000 tanks at the 5,000 commercial filling stations in Ontario. The comprehensive tank replacement program should eliminate all unprotected tanks (John Gerdells, personal communication, 1992). Legislation covering private underground storage tanks (an organization or individual with tanks for their own use) was passed in 1988. In 1990 a database listing private underground fuel storage tanks was initiated and continues to be updated.

Beak (1986) gives brief descriptions of nine incidents where wells were affected by gasoline or fumes entered the basements of houses. In some cases, sewer lines or other manmade conduits provide a route of transport for groundwater and gasoline.

2.5 Landspreading of Refinery Sludge.

Landspreading is becoming an increasingly popular method of disposal for refinery sludge. In 1978, it was the second most popular method after landfilling for disposal of refinery waste in Canada, being used for 18 % of the 196 million tonnes of such waste (PACE, 1980), and it has become more popular since. At the time, six Ontario refineries, several of them in the Sarnia region (PACE, 1980), used this method for disposal.

In this method, sludge is spread onto soil that is fertilized, cultivated and, if necessary, limed for acidity control. A loam type soil is best since clay soils tend to retain water and are difficult to till, and very sandy or silty soils may have a poor ability to absorb heavy metals. Soil covered with vegetation should not be used (PACE 1981, 1990). Sixty to eighty percent of the sludge is degraded by microbial oxidation, the rest degrades by photo-oxidation or volatilizes (CONCAWE, 1980).

Concern about groundwater contamination centres on those constituents of the sludge that do not decompose readily such as heavy metals (chromium, copper, iron, molybdenum, nickel, selenium, vanadium and zinc) and polycyclic aromatic hydrocarbons (PAHs) (PACE, 1981; Hosler et al., 1992). Although PAHs and metals are very slow to degrade or do not degrade at all, they are relatively immobile in the soil. Monitoring of soil and leachates before, during and after (close-out) sludge farming is required for an effective operation (PACE 1981).

2.6 Spills

Spills, other than from underground and above ground petroleum storage tanks, may occur during manufacturing and storage of chemicals, during transport by road or rail, or during use for resource production. Spills of wood preservatives are receiving increased attention because of well reported and relatively frequent cases of groundwater and surface water contamination across Canada (Cherry, 1987; Beak, 1986). Depending on the treatment method, large amounts of creosote (which contains PAHs), chlorophenols, or metal salts (primarily chromium, arsenic or copper) may be used at wood preservation plants. Spills have occurred at Timmins (Beak, 1986) and at Thunder Bay (de Bakker, personal communication, 1988). PCBs were spilled at a manufacturing plant in Toronto (Beak, 1986), and at a PCB-storage facility in Smithville (Proctor and Redfern and Golder Associates, 1991).

The Spills Action Centre (SAC) of the Ministry of the Environment and Energy receives and initiates responses to spills and other environmental incidents. In 1991 the SAC documented 5,251 spills of which 54% involved oils or fuels, 18% were chemicals or chemical solutions, 17% wastes or wastewaters, 9% gaseous emissions while the remaining 2% were other and unknown materials. A large portion of these spills involved small quantities: 20% were less than 10 L, 58% were less than 100 L and 85% were less than 1,000 L (Ontario Ministry of the Environment, 1992a).

Adverse environmental impacts were confirmed for 14% of the spills (Figure 13). A further 43% of the spills could have a potential impact and another 43% were not considered to have any impact. Of the 711 confirmed environmental impacts, 18 were considered to cause groundwater pollution. The majority of the impacts, 458, resulted in soil contamination (Ontario Ministry of the Environment, 1992a).

2.7 Sewage Disposal and Inadequate Well Construction

Sewage disposal may contribute pathogens (bacteria, viruses and other microorganisms), nitrate and to a lesser but increasing extent, organic solvents to groundwater (Freeze and Cherry, 1979; Pye et al., 1983; OTA, 1984; Canter and Knox, 1985; Cherry, 1987). There are three potential routes for sewage to cause contamination of groundwater:

i) individual septic systems, probably the most common cause for contamination of residential wells;
ii) leaking sewer lines, an increasing source of contamination of the subsurface as these systems age and deteriorate (Pearse et al., 1985); and
iii) occasionally leaking sewage lagoons (Beak, 1986).

Ontario has about one million conventional septic systems and there is increasing evidence of contamination of ground and surface water as a result of their use. In 1990 the MOEE inspected 9,067 systems and 34% were found to be malfunctioning. It is possible that one of third of the systems pose a threat to groundwater quality (Commission on Planning and Development Reform, 1992).

A study has been conducted of the impacts on groundwater from septic tanks located on shallow unconfined sand aquifers in Ontario. The study found that the septic tanks were sources of long narrow plumes that contained elevated levels of chloride, nitrate, sodium and depressed levels of pH and dissolved oxygen. The study concluded that the minimum distance between septic tanks and water wells as currently given by regulations in North America does not adequately protect well water quality in unconfined sand aquifers (Robertson et al., 1991).

Sewage sludge can be spread over agricultural land to improve soil structure and to reduce the reliance on nitrogen and phosphorus fertilizers. However, heavy metals in sewage sludge and contamination from nitrate and bacteria are potential problems. In the Ontario Farm Groundwater Quality Survey of 1992, 31 of the 1,285 farms in the survey used sewage sludge. The incidence of contamination for the users of sludge did not significantly differ from those for the entire survey. Nitrate contamination of water was found in 13% of the wells and bacterial contamination was found in 45% (Agriculture Canada, 1992).

Risk of water well contamination is posed by shallow wells which are not adequately protected from surface runoff. In many cases, microorganisms or nitrate may come from a variety of sources, such as septic tanks, manure piles and feedlots. If the well is poorly constructed it may not be possible to differentiate with any certainty whether the well had been contaminated via groundwater or via surface runoff (Pye et al., 1983). Shallow wells, often dug, augered or driven (sandpoint) wells, are common in most of the sand plains of Ontario. The Ministry of the Environment and Energy has estimated that several hundred thousand wells are not registered and these are mainly shallow wells. Risk of water well contamination is also high in areas with a concentration of septic tanks (cottages, camp sites). A limited density of septic tanks can be tolerated without danger to groundwater but the assimilative capacity of geologic materials is highly variable

2.8 Agricultural Practices

2.8.1 Background

The Great Lakes and Ottawa-St. Lawrence Lowlands of southern Ontario (and Quebec) comprise some of the most intensively cultivated areas of Canada. Almost 70 % of Canada's corn, practically all soybeans, 20 % of cattle, and 32 % of pigs come from

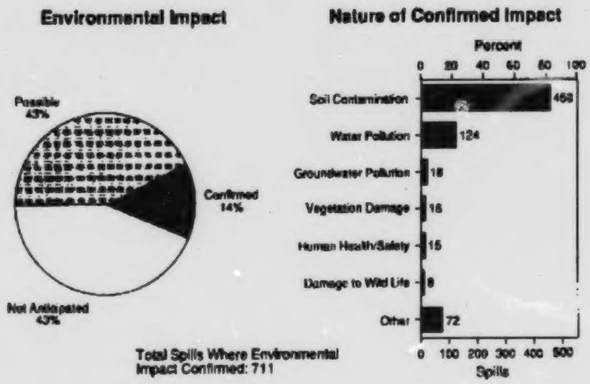

Figure 13: Environmental impacts of spills for 1991 (from Ontario Ministry of the Environment, 1992a)

this area which contains only about 8 % of all farmland in Canada (Statistics Canada, 1986, data from 1981). The most productive and most intensively cultivated area is the southwest of the province, roughly bounded by Lake Huron, Lake Erie, the western tip of Lake Ontario and Lake Simcoe. The main threats to groundwater quality come from the application of pesticides, commercial fertilizers and animal manure.

Of the three main components of agricultural fertilizers, potassium, phosphorus (as phosphate) and nitrogen, the first two interact strongly with the soil and the aquifer medium and move very slowly in soil and groundwater (Freeze and Cherry, 1979; Cherry et al., 1984). Nitrate, on the other hand, is relatively soluble and moves readily in the subsurface environment. This property, together with the extensive and increasing use of fertilizer in agriculture, and with the common practice by farmers to use more than is needed, make nitrate one of the most common and most worrisome of groundwater contaminants in agricultural areas (Shelton et al., 1988a). The drinking water limits for nitrate have been established in most jurisdictions, including Canada, as 10 mg/L NO_3 (expressed as N) primarily because of the threat of methaemoglobinaemia to infants (CCREM, 1987).

Brief overviews on the effects of fertilizers and pesticides on groundwater have been prepared by Beck (1988), Singer (1988), and Shelton and Wall (1988). Studies of contaminants in groundwater due to agricultural activities have been conducted by the Ontario Ministry of the Environment (1985, 1986a), Frank et al., (1979, 1987a, 1987b) and Shelton et al., (1988a,b).

A comprehensive survey of rural groundwater quality was conducted between October 1991 and March 1992 (Agriculture Canada, 1992). The results from this survey are summarized in the following section.

2.8.2 Ontario Farm Groundwater Quality Survey

This province-wide survey was initiated by Agriculture Canada and involved the collaboration of eight different groups. In the first phase groundwater samples were collected during the winter from 1,285 randomly selected farm wells and 144 multilevel monitoring wells. To examine seasonal variation of groundwater contamination in agricultural areas, the second phase will use data collected during July and August, 1992.

The purpose of the survey was to determine the concentration of contaminants from agricultural activities and to relate the contamination to various physical factors. The samples were analyzed for common groundwater contaminants such as nitrate-nitrogen (nitrate-N), total and faecal coliform bacteria and five commonly used and persistent pesticides. Analyses were also conducted to determine the petroleum derivatives benzene, toluene and xylene (BTEX). The relationships between contamination and the following physical factors were investigated: age, depth and type of well; soil type; distance from well to potential contaminant sources; and type of agricultural activity (mixed farming or corn, soybean, tobacco, etc.).

By selecting nearly 1,300 wells throughout the province, the results provide general trends in drinking water quality for farm families. The survey found that 37% of the sampled wells contained one or more of the target contaminants above the maximum acceptable concentration (Table 2). The most widespread cause of contamination was bacteria which was present above accepted limits in 31% of the wells. Following bacteria, nitrate-N was most frequent with 13% of the wells having concentrations above the 10 mg/L limit. The BTEX petroleum derivatives were not detected in any of the 160 wells identified as high risk for contamination by BTEX (risk defined by proximity of well to fuel storage tanks).

Although detectable pesticides were present in 7.5 % of the wells, only one well exceeded the interim maximum acceptable concentration for pesticides (high metolachlor). Most of the wells with detectable levels of pesticides contained atrazine and/or its metabolite d-ethyl atrazine (Table 3).

The results were used to investigate the relationships between occurrence of contamination and various physical factors. Concerning age, type and depth of the well it was found that: older wells (greater than 60 years) were more frequently contaminated; a greater incidence of contamination occurred with dug or augered wells than with drilled or driven (sandpoint) wells; and shallower wells were more susceptible to contamination.

Other physical factors included soil type and type of agricultural activity. A greater frequency of nitrate-N contamination was found in highly permeable soils such as gravelly soils or sands. However, a higher incidence of bacterial contamination occurred in the less permeable loamy soils. The type of agricultural activity was not a major factor determining the occurrence of contamination (Agriculture Canada, 1992).

To investigate the relationship between agricultural activities and contamination in the farm wells, multilevel monitoring wells were installed in 144 actively cultivated fields. In general, the results from the multilevel wells showed higher incidences of contamination under the active fields than in the farm wells. Bacteria above acceptable limits were found in 65% of the multilevel wells and nitrate-N above 10 mg/L was found in 44% of these wells. These results indicate a strong correlation between shallow groundwater contamination under the farm field and contamination in the well.

Only 4% of the multilevel wells contained trace concentrations of pesticides. The results of the pesticide analyses from both the water wells and the multilevel monitoring wells indicate "that the pesticides considered in this survey have not become significant groundwater contaminants" (Agriculture Canada, 1992, p. 86).

2.9 Road Salt

As in all of eastern Canada, road salt is a source of groundwater contamination in Ontario (road salting is not often used west of the Ontario-Manitoba border). Up to 50 % of all complaints about well water quality at regional and district offices are related to road salt. Two hundred and fifty milligrams per litre of chloride is the maximum desirable concentration of the Ontario Drinking Water Objectives (Appendix C). Chloride levels often rise and fall cyclically, following the application rate with a time lag of 80 to 200 days (Cross, 1980).

Salt in groundwater may make it unsuitable for human consumption and some industrial applications. Groundwater contaminated with salt may also discharge to urban streams causing degradation of water quality. Concerning human health, sodium has been strongly linked to hypertension and associated indirectly with hypernatraemia (Howard and Haynes, 1993; Howard and Beck, 1993).

Salt contamination of drinking water is often limited to wells near paved roads (less than 30 m distance from the road) and is more likely in areas with many wells along the roadside, areas with heavy salt application (i.e. urbanized areas), and

Table 2 General Distribution of Contaminants in Farm Wells of Ontario

Contaminant	Wells Tested	Wells Above Acceptable Limits	
	Number[*]	Number	Percent[#]
Bacteria			
Faecal Streptococcus	405	60	14.8±3.5
Escherichia coli	330	58	17.6±4.2
Enterococcus spp	129	29	22.5±7.4
Total coliforms	1289	327	25.4±2.4
Faecal coliforms	1288	256	19.9±2.2
Total &/or faecal coliform	1288	393	30.5±2.6
Nitrate	1290	163	12.6±1.8
Mixed Contamination			
Bacteria &/or nitrate	1284	473	36.8±2.7
Bacteria & nitrate	1283	83	6.5±1.4
Pesticides			
Alachlor	1285	0	-
Metolachlor	1285	1	0.1
Atrazine	1285	0	-
d-Atrazine (atrazine metabolite)	1285	0	-
Metribuzin	1285	0	-
Cyanazine	1285	0	-
BTEX (Petroleum derivatives)			
Benzene, toluene, ethyl benzene, p-xylene, m-xylene, o-xylene	157	0	-

[*] Number for which results were available.

[#] ±95% confidence level.

(from Agriculture Canada, 1992, p. 28)

Table 3 **Occurrence of Pesticides in Sampled Ontario Farm Water Wells**

Wells with Detected Residues	ALA[*]	METOL	ATR	DATR	SEN	CNZ
Frequency (# of wells)	0	11	86	51	5	1
Frequency (% of all wells)	0	0.9	6.7	4.0	0.4	0.1
Maximum Concentration (μg/L)	0	110.0	18.0	4.4	16	5.7
Mean Concentration (μg/L)	0	14.3	1.1	0.50	3.8	5.7
Recommended Maximum Concentration (μg/L)	5	50	60	#	80	10
Minimum Detection (μg/L)	0.2	0.2	0.05	0.1	0.05	0.2

[*] ALA=Alachlor, METOL=Metolachlor, ATR=Atrazine, DATR=D-ethyl atrazine, SEN=Metribuzin, CNZ=cyanazine.

# Included with total for atrazine.

(from Agriculture Canada, 1992, p. 56).

areas where topography favours contamination (e.g. steep contours, hilly terrain). Additional factors include shallow, dug or poorly constructed wells, and thin overburden.

In the past, uncovered storage piles at highway patrol yards have been a frequent source of groundwater contamination by road salt. An earlier report (Pupp, 1985) gave an estimate of 250 patrol yards in Ontario where there was the threat of contamination. Although most storage piles are now covered, the results from monitoring at one patrol yard in northern Ontario indicate that losses of salt to the environment still occur. Approximately 1 to 4 tonnes per year are lost due to surface runoff and 3 to 4 tonnes per year are lost due to washing of the salt trucks (Jim Sutton, personal communication, 1992). Water wells located at Ministry of Transportation patrol yards and highway picnic areas are now sampled for major ions twice a year (Beck, 1988).

The main cause of contamination is the use of salt as a de-icer on provincial, regional and municipal roads. For example, during the winter of 1987-88, the province's 26,834 km of roads received 540,000 tonnes of salt. In northern Ontario, annual application of salt ranges from an average of 15 tonnes per 2 lane kilometre to 40 to 50 tonnes per 2 lane kilometre along the hilly areas of the north shore of Lake Superior (Jim Sutton, personal communication, 1992). The Ministry of Transportation is conducting research on the environmental and economic impacts of de-icing alternatives such as calcium magnesium acetate (Brian Gaston, personal communication, 1989).

Studies of the impact of road salt on groundwater quality have been conducted in the Metropolitan Toronto area. Pilon and Howard (1987) report chloride concentrations as high as 13,000 mg/L in shallow subsurface water adjacent to a highway in Toronto. In an effort to determine the fate of the 100,000 tonnes of road de-icing chemicals applied in the area, Howard and Haynes (1993) used a chloride mass balance for the Highland Creek watershed. This urban watershed receives 10,000 tonnes of salt per year. The chloride mass balance showed that only 45% of the salt is removed with the rest accumulating in the subsurface. If present application rates continue, average concentrations of salt in groundwater could reach 426±50 mg/L in 20 years. According to Howard and Beck (1993) "road de-icing salts appear to be the primary cause of elevated chloride in the shallow groundwaters of the Metropolitan Toronto and Region watershed".

Complaints of contamination of wells by road salt are resolved by the Ministry of the Environment and Energy and the Ministry of Transportation. Wells may be relocated, drilled deeper, or a water treatment system may be installed.

2.10 Nuclear Power Generation and Nuclear Waste

The accidental release of radioactive material from existing temporary repositories or from future permanent repositories is a groundwater quality concern. Ontario derives 53% of its electricity from its nuclear reactors (11,687 MW net capacity) (Ontario Hydro, 1992). Sources of radioactive waste include the operating nuclear stations as well as 9 research reactors, 8 storage sites for low-level radioactive waste (two of them old unlicensed sites), tailings from operating and closed uranium mines at Elliot Lake and Bancroft and refining and processing wastes from facilities at Port Hope and Blind River (near Elliot Lake) (Figure 14). Nuclear energy and other nuclear industries (production of radio-isotopes) are a major industry in Ontario and disposal of nuclear waste is a major task.

There is at present no permanent disposal facility for high-level waste (primarily spent fuel) anywhere in the world; spent fuel in Canada is temporarily stored in storage bays (Aikin et al., 1977; Gillespie et al., 1984). About 1,900 tonnes of spent fuel (calculated as uranium) from nuclear generators is produced every year in Ontario; 9,200 tonnes had accumulated to the end of 1986 and a total of 31,300 tonnes was forecast for the year 2000 (Gillespie et al. 1984).

In addition, estimates of 10,000 m^3/a (Table 4) have been provided for the production of low and intermediate level radioactive waste in Canada (Cameron et al., 1986; Franklin, personal communication, 1987). Ninety percent of this waste is generated in Ontario. The total volume of low and intermediate level waste stored in Canada (not including wastes from uranium mining to be discussed in the next section) is estimated to be about 1.2 million m^3, and is forecast to increase to 1.7 million m^3 by 2025 (Cameron et al., 1986; Franklin, personal communication, 1987). Over half of this waste has come from uranium refining and processing by Eldorado Ltd. at Port Hope.

Of the three storage sites licensed by the Atomic Energy Control Board (AECB) for low and intermediate level wastes, the two at Welcome and Port Granby are now closed. The third storage facility is located at Chalk River Nuclear Laboratories (CRNL), where waste from outside facilities is being accepted. Localised contamination with radio-isotopes has occurred at all three facilities (Grisak and Jackson, 1978; Jackson and Inch, 1980; Killey and Devgun, 1986; Dixon, 1985; Beak, 1986). Some of the contaminants at these sites move very slowly relative to groundwater and all are being closely monitored. Soil contamination has also occurred at two locations (Port Hope Town and Scarborough/Malvern) that were not licensed.

At present, the AECB has licensed only temporary storage of radioactive waste. The AECB advocates permanent disposal but has not yet been asked for a permanent disposal license. A federal task force, reporting to the Minister of Natural Resources, has been created to identify a strategy for siting a low-level radioactive waste disposal facility in Ontario (Energy, Mines and Resources, undated). There are five communities that have volunteered as potential sites for the disposal facility. They include Geraldton, Deep River, Newcastle, Hope Township and Port Hope (Figure 14).

Table 4 **Annual Generation of Low and Intermediate Level Waste in Canada**

Source	Approximate Annual Volume (m^3)
Uranium refining and processing and fuel fabrication	2,200
Use of radio-isotopes in medicine, industry, research, etc.	350
Nuclear generating stations	4,600
Research laboratories and radio-isotope processing (primarily AECL)	1,660
Manufacturing wastes with incidental natural activity (e.g. abrasives, phosphogypsum tailings)	1,550

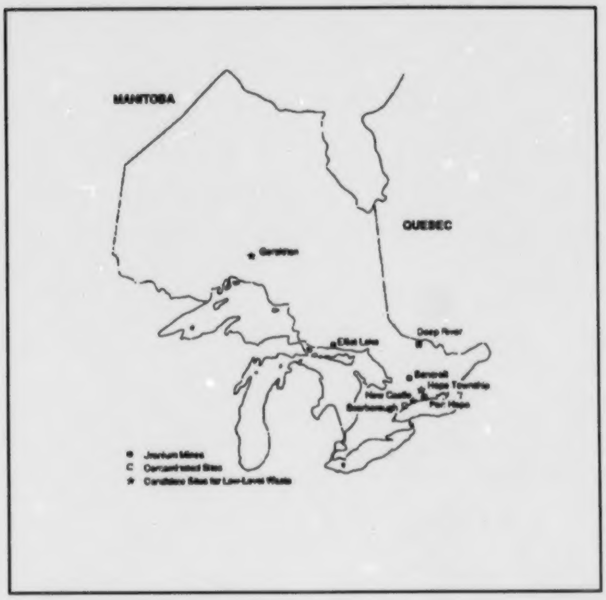

Figure 14: Sites associated with nuclear waste in Ontario.

The most controversial aspects of radioactive waste management will be the disposal of spent fuel, decommissioning of plants and the disposal of high level waste in general. For disposal of such waste, Canada is concentrating its effort on the option of burial in deep plutonic rock in the Canadian Shield.

The temporary storage of radioactive waste is one of the most closely supervised and regulated of all potential sources of groundwater contamination. The greatest challenge may be to establish facilities for the permanent disposal of radioactive waste that are safe, satisfactory to the public and economically feasible. Research programs by Atomic Energy of Canada Ltd. (AECL) are centred at Pinawa in Manitoba for disposal of high level waste, and at CRNL for low and intermediate level waste.

2.11 Mining

Mining is one of the major resource industries in Ontario. The major mining regions in the northeastern portion of the province are Elliot Lake (for uranium), the Sudbury basin (base metals, cobalt, platinum and others), Kirkland Lake/Cobalt (gold and silver), and Timmins/Porcupine (base metals, gold and silver). In the northwestern portion they are Algoma (iron), Longlac/Manitouwadge (base metals, silver), Red Lake (gold, silver, base metals, iron) and Hemlo (gold) (Marshall, 1982) (Figure 15). Non-metallic mineral deposits such as sand and gravel, talc, gypsum, nepheline syenite, silica, calcite and barite are exploited mainly in southern Ontario. Salt is mined in the Windsor and Sarnia area.

The prime environmental challenge for mining is the management of tailings and waste rock. Tailings are impounded within a closed basin as slurries typically containing 30 wt% solids. To enhance the structural stability of the tailings some of the water is collected and removed after deposition leaving the solids exposed to the atmosphere. Oxidation of sulphide minerals produces acid which may cause dissolution of radionuclides and other metals. The acidic water containing the contaminants can move along groundwater flow paths that discharge to lakes or streams (Cherry, 1987; Blowes and Cherry, 1991).

Although, in most mining regions, there are abundant surface water supplies and aquifers are likely to be shallow, small, isolated and seldom used for water supplies, groundwater contamination due to seepage from tailings ponds is a major concern. The main threat is ultimately to surface waters and aquatic life; the importance of groundwater (and of the overlying vadose zone) lies in its role as a route of transport and a zone of attenuation of contaminants.

The main sources of acid mine drainage are base metal and uranium mines. A sulphur content of 1% or more together with insufficient carbonate buffer seem to be the required conditions for acid drainage to occur (Ferguson and Erickson, 1987). For example, uranium tailings at Elliot Lake (sulphur content of 3.2 to 6 % pyrite (Melis, 1983)) produce acid mine drainage while uranium tailings at a closed mine in Bancroft (sulphur content 0.6 % and a higher buffering capacity) do not.

Hawley (1979) has reported on the composition of mine tailings in Ontario. He reports an average concentration of 2.8 % sulphur in tailings from base metal mines. Waste rock may produce acid drainage more readily than tailings because of its higher porosity (Errington and Ferguson, 1987).

Gold, silver and iron mines (with an average sulphur content of 1.1, 0.5, and 0.9 % respectively) generally are not a source of acid generating tailings. The main concern from gold mines is the contamination by cyanides (from the extraction process), arsenic (concentrations in the tailings up to 7.4 %), antimony (concentrations up to 1.6 %) and some other metals.

Management and control of tailings and waste rock becomes a challenge after the mine closes. Tailings become exposed to the atmosphere and they continue to produce acid mine drainage for tens or hundreds of years (Marshall, 1982; Cherry, 1987).

Treatment of water from tailings may involve uranium tailings (National Uranium Tailings Program (John, 1987)), and other tailings that generate acid drainage (Reactive Acid Tailings Stabilization Program (CANMET, 1988)). Inventories of tailings have been produced as part of these programs (Melis, 1983; Monenco et al., 1984). According to these inventories there are about 113 million tonnes of uranium tailings in the province covering an area of about 460 ha, most of them at Elliot Lake with smaller quantities at Bancroft. In addition, there are 600 to 700 million tonnes of other metal tailings covering about 3,250 ha.

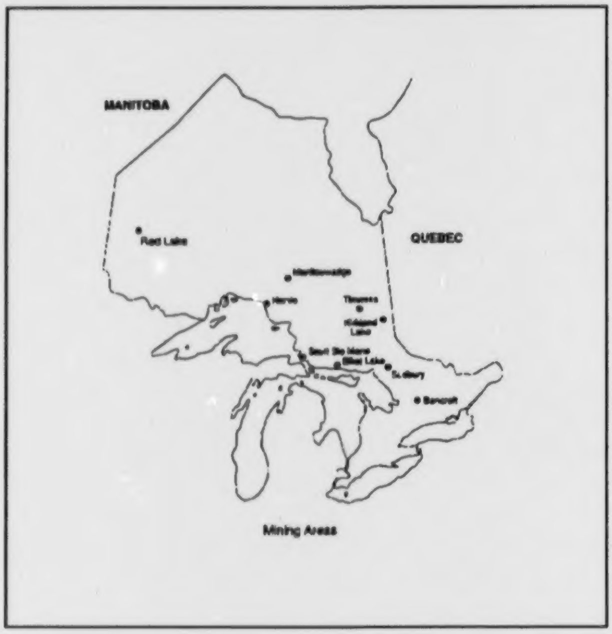

Figure 15: Major mining areas of Ontario mentioned in text.

2.12 Coal-Fired Electric Power Stations

There are five operating coal-fired electric power stations in Ontario (Figure 16) with a combined capacity of 9,000 megawatts (Berry et al., 1983a; Monserco, 1983; Ontario Hydro, 1988). Because of their need for cooling water, they are all near large bodies of water. These stations generate an estimated 900,000 tonnes of fly ash and over 300,000 tonnes of bottom ash every year (Berry et al. 1983a, Ontario Hydro 1988). At these power stations, the disposal of ash, primarily offly ash, and the storage of large amounts of coal in uncovered piles create the threat to surface water and groundwater.

Fly ash consists primarily of oxides of silicon, aluminum, iron, magnesium and calcium, with traces of boron, titanium, sodium, potassium, sulphate and phosphate and a range of other elements (Berry, 1983b; Constable and Ross, 1986). Fly ash is recovered from flue gas by air pollution control devices (e.g. electrostatic precipitators). Bottom ash consists of slag and larger particles and is much less reactive than fly ash. Much of the ash is landfilled but some may find commercial uses as construction material, filler or cement additive (Berry et al., 1983a). The station at Nanticoke uses a slurry to transport ash to the storage lagoons, while the other stations use a variety of dry techniques (Berry et al., 1983a).

A variety of elements may leach from ash and the pH may range from 4.4 to 12.4 (Constable and Ross, 1986; Chan et al., 1986 and references therein). In a detailed study of possible groundwater contamination from ash, Chan et al. (1986) investigated an ash landfill in Ontario and evaluated ten published case studies. They concluded that sulphate, chloride, calcium, iron, manganese, chromium and boron were contaminants of some concern (i.e. they were found at concentrations higher than the Canadian Drinking Water Guidelines in some portions of a plume), but, in general, the extent of leachate plumes was very limited and many elements were strongly attenuated. The mobility of different ions in groundwater (e.g. arsenic, selenium or boron) depends strongly on the pH (Cherry et al., 1984; Hickinbotham, personal communication, as quoted in Chan et al. 1986).

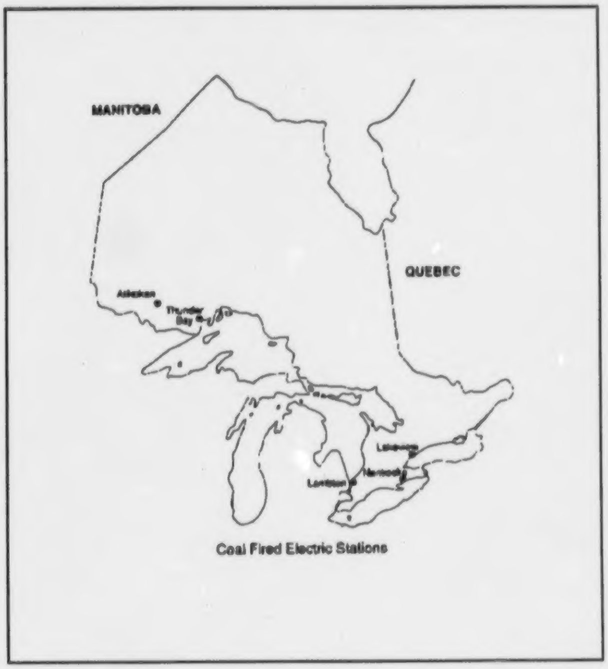

Figure 16: Coal fired electric generating stations in Ontario.

Chan et al. (1986) also found that the likelihood of contamination was diminished with deeper water tables or when impermeable covers and liners were used (if mounding of precipitation and the "bathtub effect" could be avoided). In many cases the ash had a lower hydraulic conductivity than its surroundings and groundwater tended to flow around rather than through the ash. Slurry ponds were found to represent the worst case for leachate generation and groundwater contamination. Constant saturation of the ash, influx of fresh ash, and an artificially high hydraulic head formed by the pond were the main contributing factors.

Surface runoff and leachate from coal piles at power stations is similar to runoff and leachate from coal mines and preparation plants. The primary contaminant is acid drainage, which depends on the sulphur concentration of the coal; metals and other compounds then leach because of the low pH. Dearborn Consulting (1982) lists coal pile areas at coal-fired power stations in Canada giving a total area of 66 ha for Ontario, and a total volume of 12 million m^3. At the time, leachate and runoff at Nanticoke and Lambton were collected and pumped to the ash storage area. At Lakeview, the drainage water was treated (liming and sedimentation).

2.13 Groundwater Heat Pumps

The installation of heat pumps for heating, cooling or water heating for residences has increased in recent years. According to Ontario Hydro, more than 8,000 ground source heat pumps are currently in use (Nethercott, 1992). Heat pump systems can be closed loop or open loop. In closed loop systems heat exchanging fluids such as brines or methanol are circulated through coils which are placed in one or more boreholes. Heat is extracted from (in winter) or released to (in summer) the water and earth surrounding the borehole. In open loop systems, groundwater is extracted from a well and pumped to the residence. The heat exchange occurs within the residence and then the water is disposed of.

Environmental and groundwater quality concerns have arisen with both types of heat pump systems. With closed loop systems the concern is the potential contamination of an aquifer from coils leaking heat exchanging fluids. Open loop systems require a large flow that is typically equivalent to 3 times the flow for a domestic supply. If several open loop systems are concentrated in an area, water demand may stress the aquifer and groundwater interference problems may occur. Use of wells for the discharge from open loop systems may result in the mixing of varying quality groundwater and the possible contamination of potable water supplies. Temperature changes may also alter the chemistry of the groundwater leading to quality problems. Above ground disposal creates the potential for flooding, winter icing, land erosion and silting (Nethercott, 1992). A Heat Pump Taskforce with members from the Ministries of the Environment and Energy, and Natural Resources, Ontario Hydro and the Canadian Earth Energy Association are investigating these concerns and their solutions (Geo-Analysis Inc. and Richards and Associates, 1992; Singer, 1992).

2.14 Cemeteries

Cemeteries often appear on the list of land uses that may cause the deterioration of groundwater quality. The only study in North America on the impact of cemeteries on groundwater was conducted by the Ontario Ministry of the Environment (1992b). This study collected groundwater samples from existing domestic or irrigation wells downgradient from six cemeteries located in southern Ontario (Figure 17).

The samples were analyzed for formaldehyde, the preservative used in the embalming process, and for nitrate and phosphate. Formaldehyde is a known animal carcinogen. Although neither the United States nor Canada have established drinking water standards for formaldehyde, a standard of 110 µg/L has been recommended to the U.S. Environmental Protection Agency.

The results from the sampling showed concentrations of formaldehyde ranged from 1 to 30 µg/L. Nitrate levels exceeded 10 mg/L at one location but the source of the nitrate is uncertain. The study concluded that cemeteries are not a significant source of groundwater contamination by formaldehyde (Ontario Ministry of the Environment, 1992b).

2.15 Natural Constituents

Overall, shallow groundwater used for drinking water supplies in Ontario is a good quality.

Hydrogen sulphide is found in areas with high sulphate concentrations and sulphate reducing bacteria. Such areas include Chatham, parts of the Guelph-Amabel aquifer and limestone and shales in the Ottawa and Kingston areas.

High levels of arsenic and uranium have occasionally been found in the metamorphic rocks of the Canadian Shield north of Kingston. Relatively

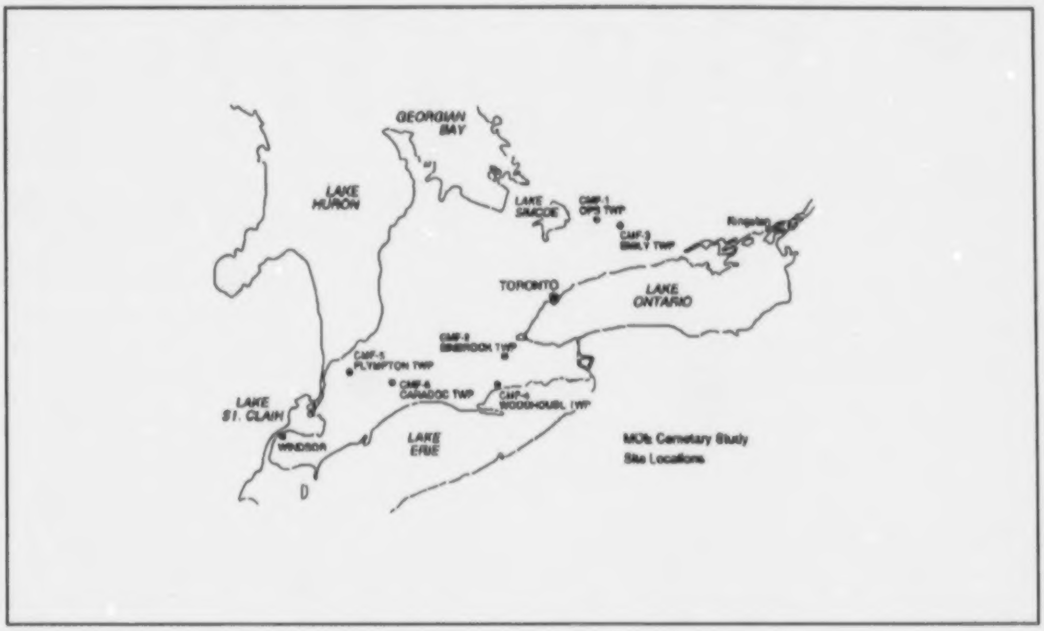

Figure 17: MOE cemetery study site locations (from Ontrario Ministry of the Environment, 1992b).

high levels of arsenic (and sometimes uranium) may also be found in bedrock aquifers in the Sudbury basin and in some sediments derived from Shield material. High levels of fluoride have been found south and west of London in some sand aquifers confined under thick layers of clay. Levels were high enough that fluoride had to be removed from drinking water supplies.

Lead and radon have been found in the Owen Sound area and somewhat higher than average levels of radon (up to 0.02 working levels in house basements) are found in the Shield between Kingston and Ottawa, and in shales in southwestern Ontario. Radon is a greater concern as a contaminant of indoor air than as a contaminant in drinking water. However, it can be transported into houses via groundwater (Cherry, 1987) or a fluctuating water table may affect its movement into houses (LeGrand, 1987).

2.16 Regional Concerns

Due to the diversity of groundwater occurrence and use in Ontario it was thought appropriate to end this section with a discussion of specific concerns in each of the regions.

2.16.1 Southwestern Ontario

The region contains some of the most intensively cultivated areas of Ontario and some large sand plains (Caradoc and Bothwell sand plains) which serve as aquifers. The combination of vulnerable surficial aquifers; shallow, dug or driven (sandpoint) wells, and the heavy application of fertilizers and pesticides (especially on corn fields) has frequently led to contamination by nitrate and pesticides (see section 2.8). Bacterial and nitrate contamination from septic systems may also occur in the same areas. The rapid increase of new subdivisions using private wells and septic tile bed systems is a great concern.

In the western part of this region, thick (up to 40 m) layers of clay/till at the surface protect underlying aquifers from the effect of surface contamination. However, naturally high levels of sulphate, sodium chloride, and hydrogen sulphide are found in bedrock aquifers. In the Owen Sound area, groundwater from bedrock aquifers sometimes contains elevated levels of lead or radon.

2.16.2 West Central

This is a region with some of the largest municipal groundwater supplies in Kitchener-Waterloo, Guelph and Cambridge. It is also a region with concerns related to the disposal of industrial waste. Major concerns include the Niagara River, with its industrial landfill sites on both sides of the river, the PCB-storage site at Smithville, the Uniroyal site at Elmira, and the proposed waste management facility of the Ontario Waste Management Corporation. In addition, cases of nitrate and bacterial contamination occur, usually connected with high-density residential development.

2.16.2.1 Uniroyal Site at Elmira

Prior to 1989, the municipal water supply of Elmira, located north of Kitchener-Waterloo, was provided by two well fields in the aquifer located beneath the town (Conestoga-Rovers and Morrison Beatty, 1990). In November 1989, the MOE analyzed water samples from municipal wells and found high levels of N-nitrosodimethylamine (NDMA), a cancer causing contaminant. The contamination was traced to Uniroyal Chemical Ltd., a company producing herbicides, pesticides and base chemicals for the rubber industry for 50 years (Bryant, 1992).

NDMA plumes are found in both the lower and upper aquifers and extend westward for about 1,200 m from the Uniroyal site. Concentrations of NDMA as high as 1,000 μg/L are found within the plume (Dames and Moore Canada, 1992). The MOE has chosen an interim drinking water guideline of 0.014 μg/L for NDMA. The other major contaminant plume, caused by chlorobenzene, is much smaller due to the lower solubility and higher retardation of chlorobenzene (Conestoga-Rovers and Associates, 1993).

Soon after discovery of the contamination, the Regional Municipality of Waterloo installed a treatment system consisting of pumping the groundwater through an advanced oxidation process. This process uses ultraviolet light to destroy the NDMA. On the Uniroyal site, a groundwater pump and treat system using similar technology began operating in 1991.

A Remedial Action Plan (RAP) has been designed on the basis that the aquifer will not be used for water supply. The RAP is based upon the following principles:

i) the aquifer will be rested, but not abandoned;
ii) municipal supply wells will not be used for water supply during remediation excep one well may be used on an emergency basis;
iii) the aquifer is to be restored to drinking water quality;
iv) the remedy is not limited to containment; restoration is the key objective;
v) the groundwater restoration program will not adversely impact the environment;
vi) it is the goal of the remedial plan to restore the groundwater to drinking water quality in 30 years. Progress will be assessed annually. Should additional measures be required to achieve this objective then they will be proposed; and,
vii) where possible, the remediated groundwater will be put to use (Conestoga-Rovers and Associates, 1993).

2.16.2.2 PCB Contamination at Smithville

In the northern outskirts of Smithville southeast of Hamilton, a former PCB transfer station has contaminated the limestone bedrock. Prior to the contamination the municipal water supply of Smithville was provided by groundwater. Water is now piped from Lake Ontario through Grimsby.

In 1978 a Certificate of Approval was granted to Chemical Waste Management Ltd. for the storage of PCBs and other hazardous wastes before being shipped out of the province. However, the main destination of the wastes became unavailable in May 1980 when the U.S. Environmental Protection Agency banned the import of PCBs. The company continued to accept PCBs until 1985 when complaints by local residents led to the closure of the site. During the seven year period, 434,000 L of liquid wastes were delivered to the site, of which 266,000 L were PCBs (Proctor and Redfern and Golder Associates, 1991).

Cleanup and securing the wastes to prevent further contamination was initiated by the MOE. The scope of the cleanup greatly increased in 1987 when dense non-aqueous phase liquids (DNAPL) consisting of PCBs, chlorobenzenes, trichloroethylene and mineral oils were found in the bedrock east of the site (Golder Associates, 1988). Since then a plume of dissolved constituents extending over 600 m south of the site in a shallow bedrock aquifer has been delineated. In the deeper aquifers dissolved constituents above Ontario Drinking Water Objectives (Appendix C) have been found. It has been estimated that 30,000 L of PCB liquid migrated through the 6 m of clay overburden into the shallow aquifer.

In 1989 an 8 well groundwater recovery and treatment system was installed to prevent the spread of the DNAPL plume in the shallow aquifer. The system has not only been successful in controlling the migration of the plume, but may be causing shrinkage or retraction of the plume. Due to the size and complexity of the site and the lack of a technology to effectively remove DNAPL contamination from fractured bedrock, the recommended Remedial Action Plan (RAP) suggests continued operation of the pump and treat system. Other aspects of the RAP include the following:

i) continued monitoring of the environment affected by the contamination;
ii) undertaking a conceptual design for a pump and treat system for the deeper aquifers;
iii) further study on the use of vertical barriers should be undertaken;
iv) the potential technologies applicable to the site should be formally re-evaluated at least every 5 years but preferably every 2 years (Proctor and Redfern and Golder Associates, 1991).

In February 1991 a mobile incinerator was brought to the site to destroy the PCB liquids and the PCB contaminated soil left on the site. The incinerator operated for almost two years before finishing in late 1992.

2.16.2.3 Hagersville Tire Fire

Tyre King Tyre Recycling Ltd., located near Hagersville southwest of Hamilton, started receiving and sorting discarded tires from retail and automotive service outlets in the mid 1960's. Approximately 14 million tires had accumulated on the site when a fire started on February 12, 1990 (Monenco Consultants Ltd., 1990a). Most of the tires were burnt and rendered to oil and chemicals by the estimated internal temperature of 2500 °C. Oil from the tires and water from firefighting operations were collected by interception ditches resulting in 2 million L of runoff water and 720,000 L of oil being collected. The amount of oil infiltrating the subsurface is not known. With the use of three water bombers and an impressive effort by local and provincial firefighters, the fire was extinguished on March 1, 1990 (Monenco Consultants Ltd. and Gore and Storrie Ltd., 1990).

The site is covered by a layer of clay soil, generally less than 0.1 m thick, overlying limestone of the Bois Blanc Formation. Fracturing and solution channels provide the major conduits for the flow of groundwater and oil in the limestone bedrock. Most of the groundwater and oil flow is limited to a number of sporadically located fractures or solution channels.

The type and degree of groundwater contamination varies. Organic chemicals such as benzene and toluene, found in the first 3 m of the bedrock, pose potential health problems whereas inorganic chemicals such as zinc and sulphur are aesthetic problems. Groundwater containing benzene above the 5 μg/L drinking water limit is confined to the burn area. A Remedial Action Plan will incorporate interception of contaminated groundwater to prevent migration. It has been estimated that contamination from the site will take 300 to 3,000 years to reach the nearest private water well (Monenco Consultants Ltd., 1990a,b)

2.16.3 Central

One of the major concerns in the region is the high level of urbanization and development. The net effect of increased residential development using water wells and septic systems is the increased probability of contamination by nitrate and bacteria and the lowering of the water table from increased withdrawal. Nitrate contamination has, in fact, occurred (e.g. Durham, Bridgenorth, Toronto area). In some cases, the uppermost aquifer can no longer be used for water supply.

Other concerns are related to the control and management of waste disposal sites (Bogie, Stouffville, Bracebridge, Pauze, etc.), spills of petroleum products, industrial spills (e.g. the PCB spill at an industrial site in Toronto) and road salt contamination. For details on many of these incidents see Beak (1986). Well-known cases of road salt contamination occurred at a municipal well for Orono from salt storage piles, and in the village of Oakwood, where about 30 wells were contaminated.

2.16.4 Southeastern

Fractured limestone aquifers have been contaminated by pesticides in Prince Edward County and by bacteria and nitrate in the Ottawa-Kemptville area where high density residential developments use septic tanks. High levels of nitrate were also found from time to time at a municipal well in Trent.

In the Petawawa sand plain of the Petawawa and Pembroke areas, shallow wells have been contaminated by road salt and petroleum products.

2.16.5 Mid Ontario

The fractured bedrock aquifers of the region have little or no overburden cover and are vulnerable to contamination by road salt (much of the new housing development takes place alongside highway corridors), leaking gasoline storage tanks and leachates from some landfills.

There is an old closed treatment facility for railroad ties at Creosote near Sudbury. Exfiltration lagoons are a common method for municipal sewage treatment and are another source of concern.

Mining may also present problems by lowering water tables but in most cases the mines are far from inhabited areas. Tailings from uranium, gold and base metal mines are also a concern. In most cases, the main impact is on surface waters and the biota therein; groundwater serves primarily as a route of transport.

In general, quality problems tend to be less severe than in the south because of lower population density and less generation and use of industrial and other chemicals.

2.16.6 Northern

Groundwater quality concerns centre around contamination from road salt since use of road salt and residential development along highway corridors is increasing, and contamination from septic tanks. Other potential concerns include gasoline leaks or spills from abandoned underground tanks and the landfills at Thunder Bay and Kenora.

While the uranium tailings from Elliot Lake are well controlled, acid-generating tailings from an abandoned base metal mine near Timmins (Kam-Kotia) have been discharging acid and metals into a nearby river.

In the case of the soil and groundwater contamination at Northern Wood Preservers in Thunder Bay, the concern for groundwater stems from its potential role as a pathway for contaminants to reach surface water. The groundwater at this site is heavily contaminated, mainly by creosote, but the main concern is the potential to contaminate Lake Superior. Work is underway to control that source of contamination.

There are three tar ponds in the region: Thunder Bay; Sioux Lookout; and at the Algoma Steel plant in Sault Ste. Marie. Aside from these, industrial threats to groundwater come from wood waste sites and other waste sites at kraft and paper mills.

PART 3 GROUNDWATER MANAGEMENT

The instruments for groundwater management are divided into the following:

(1) the legal basis for the management of groundwater resources and groundwater quality (Chapter 3),
(2) the institutions available to manage resources as well as quality (Chapter 4), and
(3) the specific programs to carry out such management (i.e. monitoring, mapping and aquifer management, data collection, technical and financial support, education and training, special programs, etc.) (Chapter 5).

While the report emphasizes groundwater quality, groundwater resource management is also discussed; in practice the two cannot be separated. Management instruments are discussed that are primarily directed at protecting surface water or drinking water but can or are being used to protect groundwater as well. It should also be recognized that, at times, groundwater is protected mainly because it is a pathway for contamination of surface water.

3.0 Legislative Instruments

3.1 Introduction

The legislative system for environmental management has three essential components. The first consists of the laws and regulations that give the force of law to a system of permits and approvals. The second is the system of permits and approvals, most of them site-specific, which are usually granted by a "Director", a person appointed by the Minister with the authority to issue approvals, permits and orders. Much of the effort of the Ministry of Environment and Energy and some other Ministries goes into granting these approvals and ensuring compliance with them. The last component consists of the policies and guidelines that describe the general directions of environmental management and protection in Ontario; these documents provide the criteria on which approvals or permits may be granted and stop-, control- or other orders may be issued.

3.2 Water Resources Legislation

In Ontario, ownership and use of water is regulated by common law which limits the right to take surface water to riparian owners (their rights being limited by the effect on the water available to downstream neighbours). Both groundwater and surface water use are restricted beyond common law by provisions of the Ontario Water Resources Act.

3.2.1 The Ontario Water Resources Act

The Ontario Water Resources Act (OWRA) is an Act that gives the Minister of Environment and Energy extensive powers to regulate water supply, sewage disposal and the control of water pollution.

3.2.1.1 Provisions on Water Use

Under the Act,

i) withdrawal of more than 50,000 L/day requires a withdrawal permit from the Minister;
ii) the Director may require a withdrawal permit for any taking of water (except for domestic use and livestock watering) if it interferes with any interest in water;
iii) the Director may require remediation if any activity (flowing well, excavation, hole) interferes with any interest in water; and
v) the Director may deny a well construction permit if a well interferes with an existing well or other water use.

Criteria followed in granting withdrawal permits are outlined in the MOEE publication "Water Management: Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment" (section 3.6.1). According to these criteria, an evaluation of the relative priority of uses is made in areas where there is insufficient groundwater to meet established and new uses. Private domestic and farm use is considered most important, generally followed by municipal use. Industrial, commercial and irrigation use is regulated by available supplies, efficiency of use and established uses.

3.2.1.2 Provisions on Water Quality

Under the Act, discharge or deposit of any material that may affect the quality of water or any well is an offence. The Act contains the following duties and requirements:

i) the Minister may examine any surface or groundwater to determine if pollution exists and the causes thereof;
ii) the Minister may apply for a judicial injunction prohibiting a discharge that causes pollution;
iii) a Director may, by order, prohibit discharge of sewage into wells or bodies of water; and

iv) the Act also requires reporting of any escape or unusual discharge of a pollutant into wells or bodies of water.

3.2.1.3 Public Sewage Systems

This part of the Act calls for the approval of a Director for any public sewage system, regulates the operation of such systems and establishes procedures for their financing.

3.2.1.4 Water Well Drilling (Regulation 612/84).

All requirements related to well construction apply to drilled, bored or dug wells.

Well Records

Well contractors must submit a water well record to the owner of a well and to the Ministry of Environment and Energy. The record provides information on location of the well, owner's name, date of construction, geological log, water quality record, well construction details, test results, well yield, water use, recommended pump setting, and name and address of the well contractor.

Well Standards

Water wells must be constructed at least 30 m (in the case of dug or bored wells without watertight casing) or 15 m (in the case of drilled wells with watertight casing) from potential sources of pollution. There are also minimum material and construction requirements for drilled, bored and dug wells.

Wells must be constructed such that the casing protrudes at least 30 cm above ground surface or above the floor of a well pit. Well water contamination caused by the entry at the well head of water originating at or near the surface may occur if the well head is buried.

Licenses for Well Contractors and Technicians

i) All persons constructing wells in Ontario must have a valid contractor's license.
ii) The business of well construction must be conducted by a well technician with a valid technician license issued by the Ministry.
iii) Plumbers and pump installers who install or supervise installation of pumps and related equipment must be licensed by the Ministry.

Flowing (Artesian) Wells

Flowing (artesian) wells must be constructed so that:

i) the discharge of water from any well casing can be stopped or regulated at any time; and
ii) there is no uncontrolled flow or leakage at any time to ground surface or to any other aquifer penetrated by the well.

If these requirements are not met, the well must be abandoned and plugged. The well contractor bears the costs for preventing uncontrolled flow and abandonment of flowing wells unless specifically released in a written contract with the well owner.

Responsibility of Well Owners

Well owners are responsible to "maintain the well at all times after the completion date in a manner sufficient to prevent the entry into the well of surface water or other foreign materials". They are also responsible to plug abandoned wells "so as to preclude the vertical movement of water or gas in the well between aquifers or between an aquifer and the ground surface.".

3.3 Water Quality Legislation

The prime legislation to regulate all environmental quality is the Environmental Protection Act and regulations under the Act. The Environmental Assessment Act, sections of the OWRA and various other legislation also can or are being used to protect water quality. All water quality legislation refers explicitly to surface and groundwater. Ontario has released policy statements and guidelines to provide assistance in the approval process.

3.3.1 Environmental Protection Act

The Environmental Protection Act (EPA) is a comprehensive regulatory scheme that gives the Ministrer of Environment and Energy the power to control the discharge of any contaminant into the natural environment in amounts, concentrations or levels exceeding those prescribed by regulation.

3.3.1.1 Waste Management (Part V)

Under this part of the Act:

i) a certificate of approval is required for every active waste management system or waste disposal site, and for the establishment, use, alteration, extension or enlargement of such a site;

ii) public hearings are required for any site serving over 1,500 users; public hearings for smaller sites may also be required at the discretion of a Director. The Director may decide that these hearings be held under the Environmental Assessment Act (section 3.3.3);

iii) for 25 years after closure of a waste disposal site, other use of the land must be specifically approved;

iv) deposits are required from all applicants, except municipalities, for waste management systems and waste disposal sites;

v) the right for compensation is established under this Part of the Act for any water user whose use is affected by the waste disposal site; and

vi) a "Waste Well Disposal Security Fund" is established from fees paid by owners of waste disposal wells; the fund is used to compensate any water users whose water is affected by a waste disposal well.

3.3.1.2 Sewage Systems (Part VIII)

Private sewage systems are regulated under this part of the EPA. Public systems are regulated under the OWRA.

For private sewage systems:

i) a certificate of approval for the construction, installation or alteration of any sewage system is required before any such system (or any building or structure which may affect a sewage system) is constructed, installed or altered;

ii) a certificate will be issued by a Director if the system:
  a) will not create a nuisance,
  b) will not be against the public interest,
  c) will not result in a hazard to the health or safety of any person,
  d) will not result in "impairment of the quality of the natural environment for any use that can be made of", and
  e) dues are paid;

iii) a permit for use and operation of the sewage system is also required following inspection of the completed system;

iv) contractors must be licensed to construct, service, repair, etc. such a system or to haul sewage; and

v) a municipality may enter into an agreement with the Ministry to issue certificates of approval and permits, to make orders, to carry out inspections, to collect fees, etc.

The Ministry has published a factsheet which sets out conditions for an acceptable sewage system. Conditions deal with acceptable soil, design of leaching beds, distance from the water table, water wells and buildings, and design and clearances for septic systems. It is implied that these conditions for an acceptable disposal system also form the conditions for regulatory approval.

3.3.1.3 Spills (Part X).

Part X of the Act sets rules for spills and unauthorized disposal of pollutants and requires the following:

i) the reporting of any spill of a pollutant that is "likely to have adverse effects on persons, property, plant or animal life or on the natural environment". The spill has to be reported to the Ministry, the municipality, regional municipality and to the owner or the person in control of the spilled material;

ii) the owner or person controlling the pollutant to do everything practicable to eliminate or ameliorate the effects of the spill and to restore the natural environment; it authorizes the Ministry to do the same, and gives employees of the Ministry right of entry and access for these purposes (subject to a judicial order);

iii) the Minister may also direct the following bodies or persons to do everything practicable to eliminate or ameliorate the effects of the spill:
  a) the owner or person in control of the affected property,
  b) the municipality or regional municipality where the spill occurs or which is affected by the spill,
  c) any public authority,
  d) any person likely to be affected;

iv) it prohibits the disposal of any pollutant or of any matter, thing, plant, animal or part of the natural environment that is affected by a pollutant except in accordance with the direction of the Minister or a Director;

v) it establishes liabilities and their limits, and delegates certain authority to municipalities, regional municipalities or designated persons or bodies; and

vi) it establishes the right to compensation and details of such compensation and establishes the Environmental Compensation Corporation to manage the process of compensation.

3.3.1.4 Deep-Well Disposal (Regulation 303)

This regulation deals with deep-well disposal of waste; disposal of brine from oil production is dealt with under Regulation 915 of the Petroleum Resources Act. Standards for the location, maintenance and operation of deep-well disposal sites are prescribed. It is stipulated that:

i) wells conform to the requirements of Regulation 915 of the Petroleum Resources Act;
ii) provisions be made to contain spills;
iii) a monitoring program be maintained for the protection of well water supplies;
iv) the monitoring be evaluated on a regular basis and additional observation wells be drilled into the receiving formation if the monitoring program indicates the need;
v) records of source, type, treatment, and volume of waste, and of injection and annulus pressure be kept; and
vi) these records be periodically reported to the Director.

No liquid industrial waste except brine is allowed to be discharged into the Detroit River Group.

3.3.1.5 Hazardous Waste (Regulation 347)

One of the main purposes of Regulation 347 is to define hazardous waste and its management. Under this regulation:

i) wastes, waste disposal sites and waste management systems are defined and classified;
ii) standards are set for the location, maintenance and operation of land-filling and incinerator sites. Standards are set for the minimum distance and isolation from the water table to prevent impairment of groundwater; monitoring is required "where there is a possibility of water pollution resulting from the operation of a landfilling site"; and, if necessary, collection and treatment of contaminants and other measures for the prevention of water pollution is required;
iii) standards and allowed locations are set for waste disposal sites where "waste is deposited without cover material being applied at regular intervals". As well as geographic restrictions (waste sites are only allowed in certain counties), minimum distances from nearest dwellings, watercourses, etc. are set;
iv) standards are set for organic soil conditioning sites where organic processed waste is incorporated into soil to improve its characteristics; distances from watercourses, water table, water wells, nearest dwellings, etc. are prescribed; and
v) responsibility is established for waste through the requirement of reports and manifests for generators and carriers of wastes.

3.3.2 Environmental Assessment Act

Under the Environmental Assessment Act (EAA), proponents of specific enterprises, activities, plans or programs are required to submit environmental assessments to the Minister of the Environment and Energy before undertaking such enterprises. The Minister has the power under the Act to:

i) accept an assessment;
ii) give approval to proceed with the undertaking;
iii) require public hearings before an Environmental Assessment Board.

Actual certificates of approval, following environmental assessment, are issued under the EPA, the OWRA or the Planning Act, as the case may be.

The Act also establishes the Environmental Assessment Board as a decision-making body appointed by Cabinet.

The Act applies to enterprises, activities, proposals, plans or programs by the provincial government, by a public body or by a municipality or municipalities. The act does not apply to the private sector with the exeption of incinerators, energy from waste facilities, waste disposal sites and those projects designated by Cabinet.

Administratively, the Minister may decide upon one of three courses of action:

i) individual assessments, which require submission of an environmental assessment by the proponent, review by the ministries and agencies of the province and publication of the review followed by submissions from the public regarding the review. The Environmental Assessment Board may hold hearings after which the Board will make a decision. Within twenty-eight days, the Cabinet (i.e. the Minister with approval from the Lieutenant-Governor) may accept the decision of the board, may vary that decision or require the Board to hold new hearings. After that, the decision is final;

ii) class assessments which follow standardized procedures; or

iii) exemptions for projects with minimal anticipated environmental effects. Those in the public interest or in emergency situations may be exempted.

The main projects involving management and protection of groundwater are waste management sites, public wells and public sewage systems. Class environmental assessments are required for public wells and sewage systems to evaluate their need, environmental impact and location. After they are approved under the Environmental Assessment Act, they still require approvals under the OWRA.

3.3.3 Ontario Waste Management Corporation Act.

This Act establishes the Ontario Waste Management Corporation as a Crown corporation. It does not establish the Corporation as a regulatory agency (Glenn and Orchard, 1986). For details see sections 4.8 and 5.7.4.

3.3.4 The Gasoline Handling Act and Code.

This Act and Code are administered by the Ministry of Consumer and Commercial Relations. The main points relating to groundwater protection and gasoline storage tanks are as follows:

i) standards for materials and installation of all new tanks are prescribed; tanks have to be protected against corrosion (cathodic protection, fibreglass, etc.); the Act also contains standards for above-ground tanks; heating oil tanks are covered under the Fuel Oil Code of the Energy Act;

ii) all existing tanks were upgraded by 1991 to satisfy new regulations (corrosion protection);

iii) all tanks at service stations, bulk plants and marinas have to be registered (since 1966). Since June 1988 non commercial outlets (e.g. police, federal facilities, etc.) also have to be registered; the initial information on the location of outlets comes from oil companies and delivery firms after which the owners are notified of the requirement to register;

iv) daily inventory control is required at all commercial outlets but the records don't have to be submitted to the Ministry;

v) if a leak is suspected following inventory control or for other reasons, the tank has to be emptied and a pressure test taken; if that test indicates a leak, the tank has to be removed;

vi) the Ministry has to be notified of the closure of a tank and the tank has to be removed within one year of closure; and

vii) automatic inspection for compliance with the provisions of the code (installation, inventory control, etc.) is not foreseen in the Act and Code; it is the owner's responsibility to comply with the provisions.

3.3.5 The Petroleum Resources Act - Regulation 915.

The main provisions in this Act pertaining to groundwater protection relate to the management of wells for hydrocarbon recovery and brine disposal. The following are the main provisions of Regulation 915 of the Act:

i) Wells for the storage of hydrocarbons, hydrocarbon recovery, production of brine, testing of subsurface structures, injection of fluids, disposal of mineral waters or for observation all require the approval of the Minister of Natural Resources;

ii) The operator of a well shall ensure that salt water, drilling fluid, oil, refuse or flammable products from the well do not create a hazard to public health and safety, or contaminate any freshwater horizon or body of water;

iii) Any disposal of mineral water in an underground formation requires the approval of the Minister;

iv) Wells for the disposal of mineral water shall be cased and cemented to prevent the mineral water from entering any formation not approved for disposal;

v) The operator of a dry well is required to plug the well;

vi) The Minister may require a discontinued well or one "delayed for an unreasonable period of time" to be plugged; if the order is not followed, the Minister may take possession of the well and have it plugged;

vii) A well shall be plugged so as to:
a) protect any potential oil or gas producing horizon,
b) prevent the migration of oil, gas or water from one horizon to another,
c) seal off horizons from those above and below. Furthermore, before a well is plugged, notice has to be given to an inspector about the manner of plugging;

viii) The operator of a well for disposal of mineral water shall keep a record of:

a) the volume of injected fluid,
b) the source of the fluid,
c) the average daily injection rate and pressure and forward an annual summary to the Minister.

Brine may be discharged into a lost circulation zone of the Detroit River Group but not within 8 km of the St. Clair River. Lost circulation zones are zones within a geological formation "into which wastes can be discharged without positive injection pressure at the surface", basically porous and permeable zones where the waste can be injected without apparent increase of pressure head.

3.3.6 The Environmental Bill of Rights

In October 1991, the Minister of the Environment announced the creation of the Task Force on the Ontario Environmental Bill of Rights (EBR). The Task Force was made up of representatives from the business community, environmental groups and the government. In June 1992 the Task Force submitted its report and the proposed EBR. The draft EBR was then reviewed by the public and their recommendations incorporated. The EBR received Royal Assent in December 1993 and was proclaimed as law on February 15, 1994. It will take 12 months for the Ministry of Environment and Energy to become subject to all components of the EBR.

The terms of reference of the EBR Task Force included the following policy objectives and principles:

i) The public's right to a healthy environment;
ii) The enforcement of this right through improved access to the courts and/or tribunals, including an enhanced right to sue polluters;
iii) Increased public participation in environmental decision-making by government;
iv) Increased government responsibility and accountability for the environment; and
v) Greater protection for employees who "blow the whistle" on polluting employers.

The policy objectives and principles were incorporated into the EBR which consists of seven Parts. Part I consists of the preamble, definitions of terms used in the Act, and the purposes of the Act. Part II makes provisions for public participation in government decisions by creating an Environmental Registry. The purpose of the Environmental Registry is to ensure residents receive adequate information and notice when significant environmental decisions are made by ministries. In addition Part II requires ministries publicly develop and apply statements of environmental values to guide governmental decision making on the environment.

Part III establishes an independent Office of the Environmental Commissioner whose purpose is to ensure the government adheres to the statements of environmental values and the other requirements of the EBR. This Office will also be responsible for measuring the progress of the ministries in implementing the EBR.

The objective of Part IV is to standardize a method for residents to request a review of existing significant environmental policies, Acts, regulations or approvals that, in their opinion, require changes to protect the environment. Application for a review will be through the Environmental Commissioner.

Residents who wish to initiate an investigation into an alleged environmental offence can do so by applying to the Environmental Commissioner under Part V. In Part VI, access to the courts is enhanced by removing the barrier of "standing" in public nuisance actions. Also under Part VI, a new civil cause of action is created to allow residents to sue for an injunction to stop a polluter from harming public resources and/or have him develop a restoration plan. Under Part VII the protection for employees who report environmental offences is expanded ("whistle-blower" protection).

Although the Environmental Bill of Rights is meant to apply to policies proposed after the Bill is law, it was suggested by the Task Force that the EBR be applied to some existing policies. Those policies that are related to groundwater quality include the Water Management Goals, Policies and Implementation Procedures (the Blue Book), the Decommissioning and Clean-up of Sites and the Guidelines for the Resolution of Groundwater Quality Interference Problems (Task Force on the Ontario Environmental Bill of Rights, 1992).

3.4 Other Acts Relevant to Groundwater Management

3.4.1 The Planning Act and the Consolidated Hearings Act.

These Acts can be used in certain cases instead of the Environmental Assessment Act to allow for one set of public hearings for larger projects. More discussion of the Planning Act and groundwater quality protection is presented in section 5.8.

3.4.2 The Pesticides Act.

This Act requires a license for any commercial pesticide applicators, a permit for commercial application and prohibits the deposit or discharge of pesticides in a way that might harm the environment, animals or persons. According to Regulation 751 of the Act, farmers must complete a certifying course on the handling and management of pesticides every five years. It also regulates disposal of containers and establishes the Pesticides Advisory Committee.

3.4.3 The Conservation Authorities Act.

This Act authorizes the establishment, at the request of a group of municipalities, of an independent public corporation to conserve, restore and develop natural resources (other than gas, oil, coal or minerals) in watershed areas.

3.5 Permits and Approvals

Ontario manages the environment largely by a system of permits and approvals supported by guidelines which set out the basic criteria for such approvals. As most permits and approvals may be appealed and may be subject to public hearings, this system allows site-specific decisions and a great deal of flexibility. Because of their importance the different permits and approvals that are part of the OWRA or the EPA are listed in this section. In section 3.6 the guidelines are briefly discussed.

3.5.1 Permit to Take Water

This permit is required under the Ontario Water Resources Act for withdrawal of more than 50,000 L/day.

3.5.2 Certificates of Approval

Certificates of Approval are required by the Ministry of Environment and Energy for certain activities or for the operation of systems that are under the jurisdiction of the EPA, EAA or the OWRA.

A certificate of approval is required for the construction, installation or alteration of any **private** sewage system and a permit for the use of such a system is required under the EPA.

A certificate of approval is required for every existing waste management system or waste disposal site, and for the establishment, use, alteration, extension, or enlargement of such a site under the EPA. Public hearings are required for any site serving over 1,500 users; public hearings for smaller sites may also be required at the discretion of a Director of the Ministry of Environment and Energy. The Director may decide that these hearings be held under the Environmental Assessment Act.

3.5.3 Control Orders and Stop Orders

A Director may issue a "control order" to limit, control or stop the addition, emission or discharge of any contaminant into the environment. The Director may also specify what equipment is to be used and what is to be monitored or studied. A control order requires justification and 15 days notice and allows submissions before the order is issued. Control orders are also issued when there is deemed to be a potential for the addition, emission or discharge of any contaminant into the environment.

A Director may also issue a "stop order". Stop orders have to be complied with immediately. These orders may be issued under the OWRA or the EPA and have a similar function as permits and approvals; these orders may be appealed.

3.6 Policies and Guidelines

The policies and guidelines often provide the basic direction of Ontario's environmental management. The Ministry of Environment and Energy has different powers under the various acts within its jurisdiction. The Ministry can insist on the implementation of policies and guidelines when matters are under the EPA or the OWRA. When the Environmental Assessment Act or the Consolidated Hearings Act is used the Ministry can only suggest and recommend. Those policies and guidelines that have bearing on groundwater management are listed below.

3.6.1 Water Management: Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment; November 1978, Revised May 1984 (the "Blue Book").

3.6.1.1 Groundwater Quality Management

Ontario has established a set of narrative and numerical objectives for water quality which are described in the "Blue Book". Together with the system of permits, approvals and regulations, they govern the management of groundwater (and surface water) quality. The criteria determine the acceptable levels of contaminants in waste disposal sites, in attenuation zones and on "adjacent properties" and determine the required level of clean-up for various contaminants. They are also used in decisions on restoration of groundwater supplies.

In addition, the "Blue Book" has a list of "Substances with Zero Tolerance Limits", a set of substances which should be completely eliminated from the aquatic environment. Another list, "Substances with Undefined Tolerance Limits", may pose adverse effects on health or the environment and the "release of which should be evaluated on a case-by-case basis and special measures for the protection of the environment should be taken". Many industrial organic chemicals are not listed in the water quality objectives (because of lack of data on acceptable tolerances) and fall into the last two categories.

The "Blue Book" lists Ontario drinking water objectives (maximum acceptable and maximum desirable concentrations, see Appendix C), and water quality criteria for agricultural uses.

The objectives are being continuously updated, often in concert with the Canadian drinking water guidelines. Where Ontario water quality objectives for specific contaminants do not exist, MOEE may adopt guidelines from different jurisdictions.

The booklet distinguishes between regulated sources of contamination (landfills, deep-well disposal, spray irrigation, sludge utilization or disposal, septic tank systems and mine tailings) and unregulated sources (existing salt storage areas, crop fertilization, undetected or unreported leaks or spills).

For regulated sources the "Blue Book" states that "degradation of groundwater supplies will be controlled to protect existing and potential reasonable uses of water on adjacent properties". Treatment or elimination of the source may be required for existing sources; replacement of the supply may be necessary where restoration is not feasible.

Control of unregulated sources "is a difficult but important aspect of the groundwater quality management program" and "pending the result of ... studies all reasonable measures shall be taken to reduce or prevent the contamination of groundwater from these sources" and "more specific measures will be implemented in future as they become available".

In addition, the "Blue Book" mentions that urban runoff or treated sewage which is being used for groundwater recharge has to be monitored for "chemical suitability", and that applicants for waste disposal facilities may be required to monitor groundwater quality to provide background data and ensure compliance.

3.6.1.2 Groundwater Quantity Management

With regard to groundwater quantity management the "Blue Book" states the following:

i) the need to obtain a Permit to Take Water for withdrawals over 50,000 L/day;
ii) if withdrawal interferes with prior use, the permittee has to restore the affected supply or reduce withdrawal "so as to eliminate the interference";
iii) large scale groundwater development close to streams will be allowed only after due regard to the maintenance of sufficient streamflow to protect downstream users;
iv) if withdrawal from a well causes interference with streamflow, restoration of supplies is required if there is serious interference;
v) temporary supplies must be provided for short-term interference;
vi) restoration is not required if community water service is available and the interference is caused for the improvement and service of the community; and
vii) if interference of groundwater supplies is caused by construction or excavation, measures may have to be taken to restore the affected supplies.

In addition, the "Blue Book" states that:

i) withdrawals from all high-capacity wells will have to measured, and monitoring of levels in observation wells and pumping wells may also be required;
ii) artificial groundwater recharge should be encouraged;
iii) special measures should be undertaken to prevent uncontrolled flow of wells in areas of significant contribution to streamflow;
iv) explicit statements of groundwater conservation should be incorporated into planning policies and official plans; and
v) protection of groundwater recharge areas should be considered in development proposals.

Finally the "Blue Book" states that in the case of conflicting uses "the taking of water for private domestic and farm purposes is considered the most important use, generally followed by municipal water supply". Industrial, commercial or irrigation uses are regulated "by the availability of supply, the efficiency of use, and established uses". Pollution control, fire protection, recreation and wildlife preservation should also be considered.

3.6.2 The Incorporation of the Reasonable Use Concept into Groundwater Management Activities, Policy 15-08, (September 1986, Revised March 1993).

The document provides guidance on the implications of contaminant discharges and the reasonable use for groundwater. It deals primarily with such sources of pollution as landfills, exfiltration lagoons and large subsurface sewage systems, all of which require approvals for their establishment, operation or extension.

i) Before a project is approved, the quality of groundwater is to be evaluated for the site, the attenuation zone around the site, and the adjacent property. Reasonable use must be preserved for the adjacent properties during operation and after closure of the site.

ii) Reasonable use is decided on a case-by-case basis. It is based on:
  a) present use,
  b) potential use, and
  c) amount and quality of groundwater present.
  Usually, reasonable use means domestic consumption but use of soil for agricultural purposes or use of the subsurface for sewers, conduits, etc. may also be considered.

iii) The decision on reasonable use usually rests with the regional director but may be subject to a public hearing;

iv) The guiding principles in the decisions are:
  a) waste disposal should not substantially degrade groundwater supplies,
  b) all attenuation capacity should not be used by a single source,
  c) contingency plans should exist for future environmental impacts,
  d) attenuation should be based on the Ontario water quality objectives (Appendix C) and background levels,
  e) differences in behaviour of solid and liquid waste-disposal facilities and the movement of liquid and gaseous contaminants in groundwater and the unsaturated zone should be taken into consideration, and
  f) certain environments will be unsuitable for waste disposal.

v) The increase in concentration of contaminants must not exceed 25% (health related parameters) or 50% (non-health related parameters) of the difference between background levels and the Ontario water quality objectives.

vi) If a contaminant concentration exceeds 100% of a water quality objective and the concentration cannot be reduced, the landfill should be closed.

3.6.3 The Resolution of Groundwater Quality Interference Problems, Policy 15-10, (September 1986, Revised March 1993).

This document gives guidelines on the extent of clean-up and restoration where groundwater has been contaminated by activities that do not have a Certificate of Approval. It is based partially on the provisions of Part X of the Environmental Protection Act. It states that it is the policy of the Ministry of Environment and Energy to clean up and restore the environment.

Furthermore it states that:

i) the MOEE has jurisdiction over clean-up and restoration but the person causing the spill or being in control of the pollutant is responsible for the costs;

ii) the MOEE can require cleanup and restoration of contaminated supplies of groundwater;

iii) resolution of interference problems does not depend upon available funds from the person causing the interference or the person affected;

iv) an action plan should be prepared for investigation, clean-up and restoration;

v) a cost/benefit assessment of the action plan should be conducted and appropriate action should be taken as quickly as possible;

vi) level of cleanup will be decided on a case-by-case basis; factors affecting such a decision (available supplies, difficulty of clean-up, costs, toxicity of contaminants, etc.) are also listed; and

vii) temporary and permanent supplies (restoration) would be provided if:
  a) the problem is neither self-induced nor of natural cause,
  b) the contamination is significant and derives from an outside source or a third party, and
  c) any of the following conditions apply:

Ontario drinking water objectives (Appendix C) for health related parameters are exceeded; at the discretion of a Director if non-health related parameters are exceeded; or upon advice of a Medical Officer of Health or veterinarian.

Details of implementation and operation of the policy are described in two appendices:

i)Appendix A: Implementation Procedures and Timing of Ministry Response to Complaints About Contaminated Water Supplies (includes descriptions of categories of contamination problems and preparation of the action plan).

ii)Appendix B: Operational Considerations (includes descriptions of the action plan and cost/benefit assessment, considerations in determining scope of investigation and cleanup and method of temporary and permanent water supply restoration).

3.6.4 Guidelines for the Decommissioning and Clean-Up of Sites in Ontario.

These guidelines give detailed steps for site decommissioning and clean-up. They are meant to apply to "all provincially, municipally and privately owned sites and facilities to be closed down at which environmental contamination may have taken place". This "includes industrial facilities, transportation facilities and institutions such as hospitals and laboratories". They may also be used where remedial action may be necessary after abandonment, e.g. coal gasification plants or other old contaminated sites. In certain cases (waste disposal sites or facilities containing radionuclides) other criteria apply.

Planned, phased procedures with definite time tables and public communication and consultation are required. While in principle clean-up should proceed to ambient background levels, the use of other relevant MOEE policies and guidelines, the application of clean-up criteria developed in other jurisdictions, or development of site- specific clean-up criteria (all of them dependent upon the approval of the MOEE) may be acceptable. Consultation with and approval from the Ministry and other agencies such as the Ministry of Health, the local Medical Officer of Health, the Ministry of Labour and the municipality is required. Where appropriate, public review may also be required.

3.6.5 Resolution of Well Water Quality Problems Resulting from Winter Road Maintenance.

This MOEE policy manual summarizes the cost-sharing arrangements when a water supply has been affected by road salt from winter road maintenance. It states that, after examination and evaluation by the MOEE regional office, the cooperating road authority or the MOEE regional office will take action through the homeowner; MOEE will refund 75% of the cost, while the road authority (if it participates) may pay the other 25%. The solution may involve the drilling of a new well, increasing the depth and length of casing of an existing well or installing a reverse osmosis unit. Where more than 5 households are involved, refunds will be paid from the Private Services Funding Program.

4.0 Institutional Instruments

The agency primarily responsible for groundwater management and protection is the Ministry of Environment and Energy (MOEE). Because of the nature of their activities, the Ministries of Agriculture and Food, Consumer and Commercial Relations, Natural Resources, Transportation and Health are also involved with specific aspects of groundwater management. Finally, several Crown agencies and management boards have a role to play though their management of programs that may have an impact on environmental quality.

4.1 Ministry of the Environment and Energy

Environmental Monitoring and Reporting Branch, Science and Technology Branch and the regional offices are the main groups within the MOEE involved in groundwater management (Figure 18). Other groups with groundwater responsibilities are the Environmental Assessment Branch and the Approvals Branch. Interaction between government and the public is facilitated by several committees, which are formally part of MOEE.

The regional offices of the MOEE act with a great deal of independence from the Ministry's headquarters. They issue permits and approvals, watch over their implementation, and provide most of the assistance and technical advice. The central offices develop laws, regulations, policies and guidelines. They also monitor the environment and collect and keep inventories relevant for environmental management.

4.1.1 Environmental Sciences and Standards Division

4.1.1.1 Environmental Monitoring and Reporting Branch

In this Branch, the Drinking Water Section plays the only role in groundwater management. The main source of expertise and activity related to groundwater is the Groundwater Group. The Branch provides advice and consultation to the regional offices, to other groups within the Ministry and to other ministries on technical matters of groundwater management.

Copies of well records are kept with the Branch as well as with the regional offices.

Groundwater Group

i) The Groundwater Group undertakes special surveys and studies to monitor the occurrence and fate of contaminants in groundwater (e.g. agricultural chemicals, road salt, radionuclides and acid rain). Monitoring as a result of specific complaints is carried out by the regional offices. Plans for a program to monitor groundwater quality have been drawn up and the program is presently under consideration.

ii) The Groundwater Group coordinates the Ministry's water well management programs (sections 21 and 22 of the OWRA and Regulation 612/84). The Group also issues licenses to water well contractors and water well technicians.

iii) The Groundwater Group provides technical advice to groups within the Ministry and in other ministries on groundwater research programs within and outside the Ministry (e.g. research on road salt to the Ministry of Transportation). It also provides advice on the development of laws and regulations (e.g. Gasoline Handling Act, Petroleum Resources Act, etc.) and for environmental assessment.

iv) The Groundwater Group has been responsible for the production of the groundwater probability maps, water resources reports and bulletins, maps of major aquifers, and the groundwater susceptibility maps.

v) The Groundwater Group provides some guidance and support to the well drillers training program at the Sir Sanford Fleming Community College in Lindsay (the only such program in Ontario).

Assessment Group

The Assessment Group of the Drinking Water Section currently (1993) monitors 120 municipal water supplies as part of the Drinking Water Surveillance Program (DWSP). Twenty-two of these are groundwater supplies and six are mixed supplies. About 180 organic and inorganic parameters are measured and the program incorporates extensive quality control.

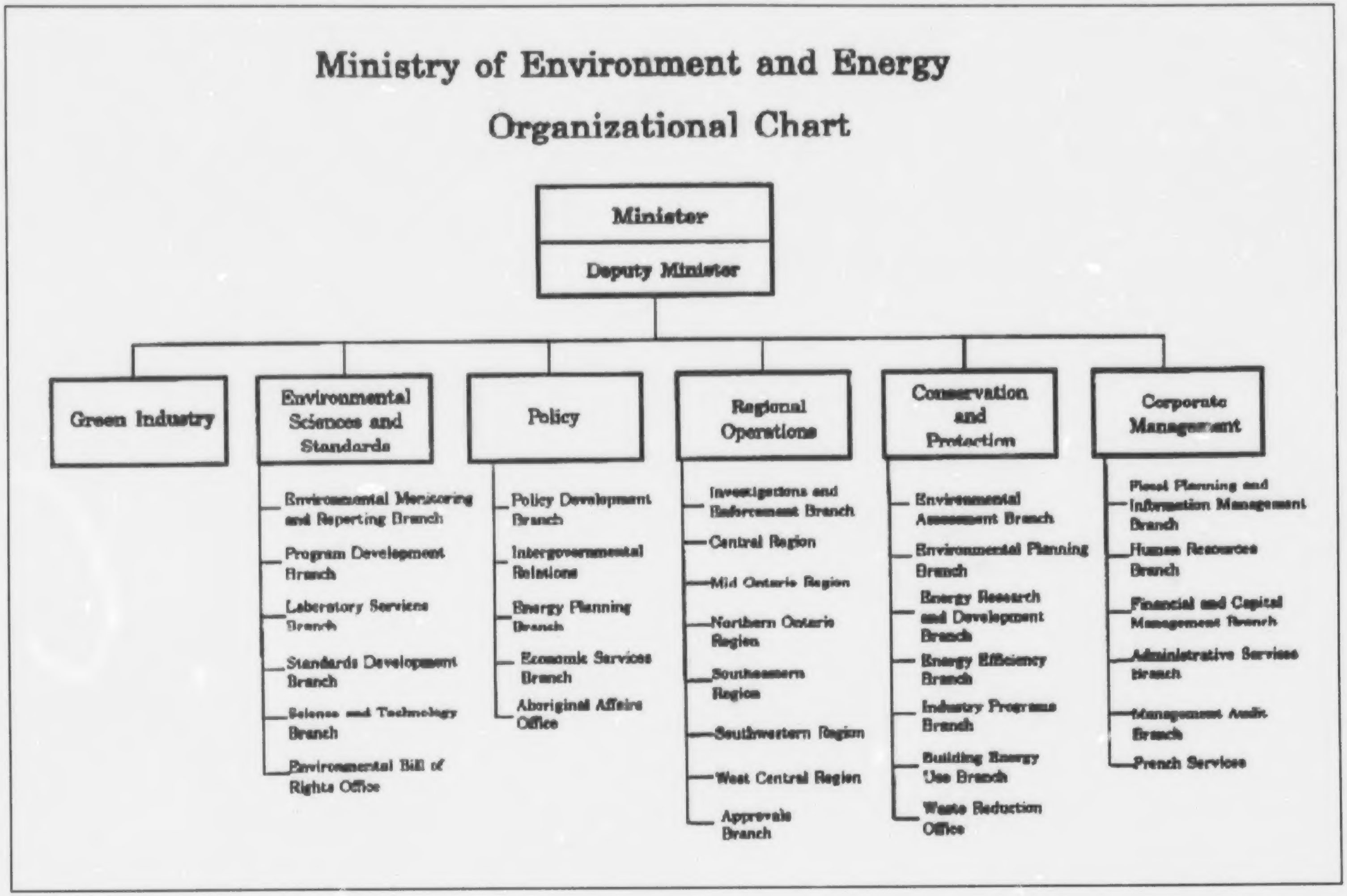
Ministry of Environment and Energy
Organizational Chart
Minister
Deputy Minister
Green Industry
Environmental Sciences and Standards
Environmental Monitoring and Reporting Branch
Program Development Branch
Laboratory Services Branch
Standards Development Branch
Science and Technology Branch
Environmental Bill of Rights Office
Policy
Policy Development Branch
Intergovernmental Relations
Energy Planning Branch
Economic Services Branch
Aboriginal Affairs Office
Regional Operations
Investigations and Enforcement Branch
Central Region
Mid Ontario Region
Northern Ontario Region
Southeastern Region
Southwestern Region
West Central Region
Approvals Branch
Conservation and Protection
Environmental Assessment Branch
Environmental Planning Branch
Energy Research and Development Branch
Energy Efficiency Branch
Industry Programs Branch
Building Energy Use Branch
Waste Reduction Office
Corporate Management
Fiscal Planning and Information Management Branch
Human Resources Branch
Financial and Capital Management Branch
Administrative Services Branch
Management Audit Branch
French Services

Figure 18: MOEE organization chart.

4.1.1.2 Science and Technology Branch

The Science and Technology Branch is responsible for developing and providing the best scientific and technological information for use in defining, supporting and implementing the Ministry's environmental priorities, policies and programs.

The Landfill Technology and Site Remediation Section is the primary source of hydrogeological expertise within the Branch. The Section develops expertise and prepares guidelines related to the hydrogeologic and engineering aspects of all waste disposal activities with an emphasis on landfills and septic systems. The environmental impacts of closed waste disposal sites and old coal gasification sites are assessed. Expertise is provided for the geophysical mapping of contaminant plumes from waste sites and in locating buried drums at illegal waste disposal sites.

4.1.1.3 Standards Development Branch

This Branch provides toxicological and risk assessment expertise for Ministry programs, policies and regulations through:

i) developing and promulgating environmental standards to protect human health and the environment;

ii) providing toxicological advice, testing and diagnostic services on the effects of environmental contaminants and pesticides; and

iii) administering the Pesticides Act and providing direction for the responsible use of pesticides.

The Pesticides Section is responsible for the administration of the Pesticides Act. It proposes regulatory amendments under the Act, develops policies and guidelines on pesticide use and provides expert advice on the Act and its regulations. It also licenses the applicators of pesticides, certifies vendors and classifies pesticides for sale and use in Ontario. The section is represented on the Ontario Pesticides Advisory Committee and liaises with other provincial and federal regulatory agencies on pesticide issues.

Environmental standards that are developed by the Branch can be reviewed by the public if requested by the Minister. The Advisory Committee for Environmental Standards (ACES) coordinates the public review and reports its findings to the Minister for consideration. In the future the public will have the opportunity to comment on all standards through the Environmental Bill of Rights.

Standards for groundwater are not set, but groundwater quality protection is considered in the development of multi-media standards for protection of human health and in the development of soil quality guidelines.

4.1.1.4 Laboratory Services Branch

The central laboratory of MOEE carries out most groundwater analyses for the Ministry including analyses required by the regional offices. Occasionally, analyses are done by commercial laboratories under contract; these contracts are supervised by the central laboratory.

4.1.2 Conservation and Protection Division

4.1.2.1 Environmental Assessment Branch

The Branch coordinates the review of environmental assessments by other branches of MOEE, the regional offices and other ministries. It also carries out most administrative activities in support of the implementation of the Environmental Assessment Act. For the administration of the Act, the Environmental Appeal Board and the Environmental Assessment Advisory Committee have been established. The Advisory Committee is a body of members of the public appointed by the Minister to advise him or her on matters relating to the Act (e.g. which projects to exempt). The Minister may ask the Committee to consult affected parties and interest groups or to hold public meetings.

4.1.2.2 Environmental Planning Branch

The Branch promotes environmentally sound planning by provincial agencies, municipalities, the private sector and the general public. It participates in provincial planning initiatives to ensure that an ecosystem approach is incorporated. It also manages the Ministry's Niagara Escarpment Program and is involved with the Niagara Escarpment Commission.

4.1.3 Regional Operations Division

4.1.3.1 Spills Action Centre

According to Part X of the EPA all spills must be reported to the MOEE. These reports are collected by the Spills Action Centre (SAC) which operates a province-wide, toll-free number 24 hours a day all year round (1-800-268-6060).

The SAC receives spill reports, keeps databases, assesses the procedures taken and gives some technical advice. It may also notify the District Environmental Officers with a request to supervise the cleanup. It may refer persons responsible for cleanup to contractors. All occurrences reported to SAC are recorded on a computerized database system called the Occurrence Report Information System (ORIS). Since 1988 the SAC has produced an annual report that summarizes all the statistics on the reported spills including type, volume, sources, environmental impact and cleanup (Ontario Ministry of the Environment, 1992a). The proclamation of Part X of EPA has led to a ten-fold increase of reported spills over previous years.

4.1.3.2 Approvals Branch

The Branch reviews, amends and issues approvals under the EPA and OWRA for the following:

i) air/noise emissions;
ii) waste processing/disposal sites and systems;
iii) wastewater collection and treatment works; and
iv) water treatment and distribution works.

Under the EPA, the Branch also administers the licensing of septic system haulers and installers. In the case of projects subject to the EAA, the Branch will provide technical review of submissions. It will also provide engineering, scientific and technical advice to other Ministry staff and expert testimony at public hearings, provincial courts and other judicial and quasi-judicial forums.

4.1.3.3 The Regional Offices

There are six regional offices which are the main contacts between the MOEE and the public for environmental investigations, proposals and permits (Figure 19). In all regions, the offices are organized into an abatement section and a technical support section. In addition, each regional office has several district offices in different locations within its region.

The district offices or the Abatement Section are the first line of contact for inquiries and complaints and for proponents of projects that require certificates of approval. The initial investigation is carried out by the District Environmental Officer or by the Abatement Section.

The Technical Support Section provides advice and support to the Abatement Section and the district offices. The staff conduct detailed investigations of complaints, if required, review proposals and provide the other groups with technical guidance. The technical guidance may concern the establishment or management of subdivisions, waste sites, etc., or the implementation of the reasonable use policy.

The Technical Support Section issues certificates of approval under the EPA (when hearings are not required), and permits to take water. The Section also monitors compliance with the water well drilling regulations under the OWRA. Usually, the regional offices do little actual monitoring work in the field. Such monitoring is done by a proponent (e.g. a waste disposal site) or by consultants under the supervision of the regional office. The Section monitors groundwater levels and keeps monitoring records and well records. A copy of the well records is sent to the Environmental Monitoring and Reporting Branch in Toronto.

The main technical expertise in groundwater lies with the Technical Support Section. Several regional offices employ hydrogeologists and several have a full-time well inspector. Others rely on environmental officers for well inspection. The groundwater staff and activities of each of the regional offices is briefly described in the following.

Region 1 - Southwestern

In the Southwestern Region there are four hydrogeologists, one well inspector and one groundwater technologist. In this region, groundwater levels are monitored at sixteen observation wells with continuous recorders. All wells are inspected and UTM coordinates recorded. Groundwater probability maps exist for Essex, Kent, Elgin, Lambton, Huron and Grey Counties.

Region 2 - West Central

In this region there are three hydrogeologists and a technician whose part-time duty is to respond to complaints related to well contractors. There is an old network of observation wells to monitor groundwater levels. At present, these wells are notbeing monitored on a regular basis. Groundwater probability maps exist for Brant, Haldimand, and Norfolk Counties.

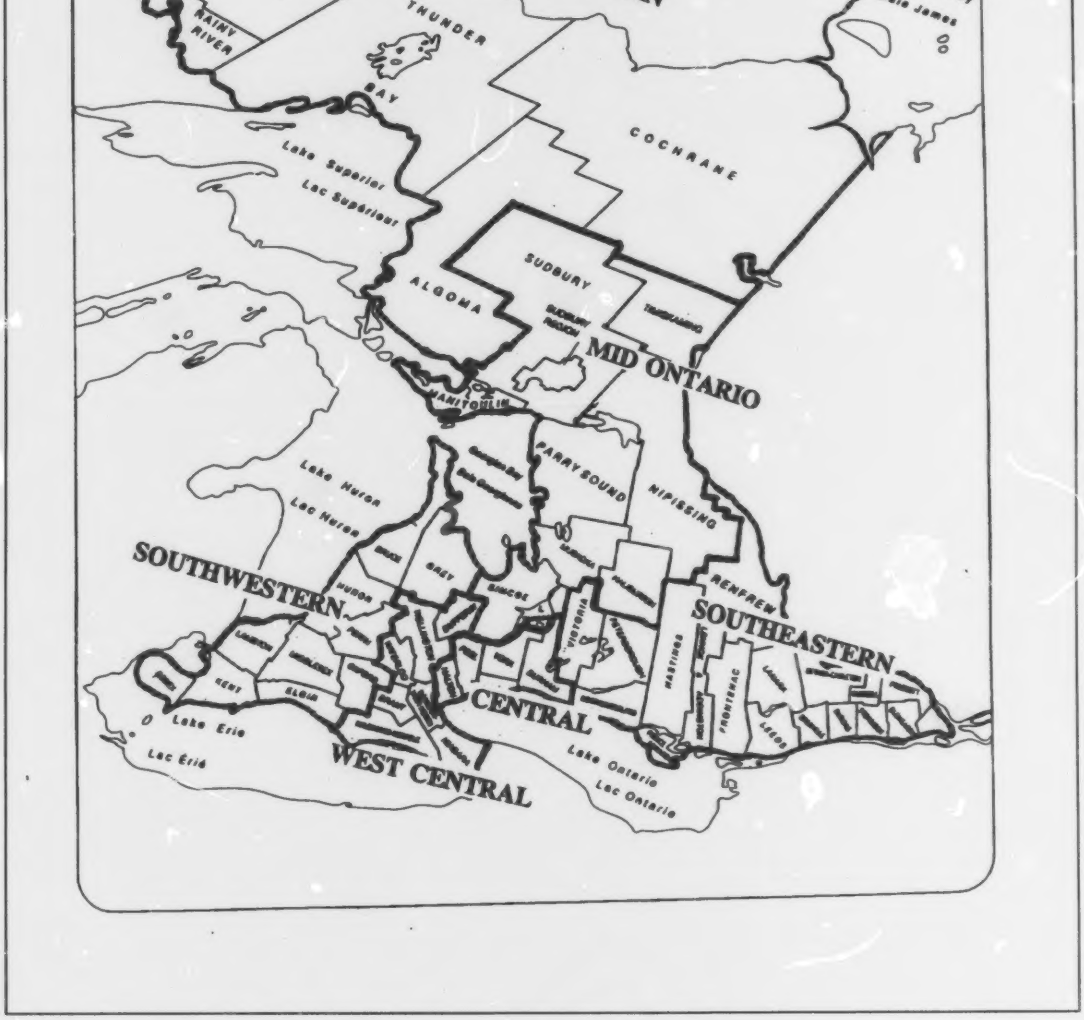
Hudson Bay
Baie d'Hudson
KENORA
NORTHERN
James Bay
Baie James
RAINY RIVER
THUNDER BAY
COCHRANE
Lake Superior
Lac Supérieur
SUDBURY
ALGOMA
SUDBURY REGION
TIMISKAMING
MID ONTARIO
MANITOULIN
Georgian Bay
Baie Georgienne
PARRY SOUND
NIPISSING
Lake Huron
Lac Huron
SOUTHWESTERN
BRUCE
GREY
SIMCOE
HURON
RENFREW
SOUTHEASTERN
VICTORIA
HASTINGS
FRONTENAC
LEEDS
KENT
ELGIN
CENTRAL
WEST CENTRAL
Lake Erie
Lac Érié
Lake Ontario
Lac Ontario

Figure 19: Map of MOEE regions.

Region 3 - Central

This region has two hydrogeologists, two groundwater technicians and one well inspector. The location of all wells (UTM coordinates) is determined but there is a backlog of wells. Groundwater levels are automatically recorded at 28 sites. Groundwater probability maps exist for Simcoe County and the Regional Municipality of Durham.

Region 4 - Southeastern

This region has one hydrogeologist and one temporary well inspector. Water levels are not currently being monitored at observation wells. There are no groundwater probability maps availiable for this region.

Region 5 - Mid Ontario

This region has two hydrogeologists and one water well inspector. The UTM coordinates of wells are determined during a site inspection by the well inspector. About 1,500 wells are drilled per year and usually there is a backlog of wells to be inspected. While some wells of an old province-wide monitoring network still exist (e.g. Manitoulin Island, Earlton), none have been monitored since 1986. There are no hydrogeologic maps or groundwater resources reports available for this region.

Region 6 - Northern

The region has two hydrogeologists. Temporary employees will periodically act as well inspectors. Groundwater levels are not systematically monitored although occasional monitoring connected to an investigation on supply and withdrawal may occur. There are no hydrogeologic maps or reports available from this region aside for one area around Marathon and whatever is available from mining exploration.

4.2 Ministry of Agriculture and Food

This Ministry is concerned with the management of soil, pesticides, fertilizers and manure. Agriculture Canada and the Ministry of Environment and Energy are charged with implementation of the federal and provincial pesticides acts respectively, and in this as well as in other areas OMAF collaborates closely with these agencies. The main branches associated with groundwater management are the Agricultural Laboratory Services Branch, which is involved in pesticide monitoring programs, and the Soil and Water Management Branch. Others with responsibility in related areas are the Animal Industry and the Plant Industry Branches. Finally, the Consumer Information Centre provides information for producers and the general public on appropriate pesticide and fertilizer use.

The Ministry develops and manages various programs related to soil and water conservation. Such programs could involve applied research, financial or technical assistance to farmers, or direct collaboration with farmers. Many of these programs have implications for groundwater management and protection and are discussed in section 5.4.

4.3 Ministry of Consumer and Commercial Relations

This Ministry implements the Gasoline Handling Act and Code that regulates the management of underground storage tanks. The Fuel Safety Branch within the Ministry develops and revises the Act and Code and administers its implementation. As such it handles the registration of installation firms and operators of tanks and records tank closures. A team of inspectors inspects storage tanks and distribution lines for petroleum products, natural gas, etc. Many larger municipalities have bylaws requiring permits for such facilities; in these municipalities, municipal inspectors carry out the inspections. The Branch also cooperates with other ministries and the federal government in the development of guidelines for underground storage tanks and keeps a limited database of leaks and spills that have occurred from storage tanks.

4.4 Ministry of Natural Resources

This Ministry is responsible for the implementation of the Petroleum Resources Act and its regulations. The Act and regulations have provisions that affect groundwater protection, primarily through required standards for oil wells, wells for the disposal of produced water and for salt caverns used for storage of gases and liquids. The Ministry develops and revises regulations under the Act, gives site-specific permits for wells, and inspects wells for construction standards (length and type of casing, avoidance of the Detroit River Group and formations containing fresh water, etc.).

The Ministry ensures that abandoned wells are properly plugged. The Ministry also keeps records of wells and well data (lithology, hydraulic head in different formations, injection rates and pressures). These records are kept at the Ministry's Petroleum Resources Laboratory and are being reviewed and placed into an electronic database. The Ministry also has a program to plug abandoned wells whose owners cannot be identified. Priority is given to wells where oil, gas or salt water may flow into different (especially drinking water) formations or into surface water.

Jurisdiction for salt mining is divided, such that underground (shaft) salt mining is under the jurisdiction of the Ministry of Northern Development and Mines while brining (leaching of salt) and subsequent use of underground caverns is under the jurisdiction of the Ministry of Natural Resources. In both cases, concerns for water contamination are addressed by the OWRA or EPA jointly by MOEE and either of the two Ministries concerned (MNR or MNDM).

The Ministry of Natural Resources through its Greater Toronto Area Branch is the lead agency in the development of a long term strategy for the protection and management of the Oak Ridges Moraine. For a more detailed discussion of the strategy see section 5.8.2.6.

4.5 Ministry of Transportation

This Ministry is responsible for road maintenance and in this context operates a program, jointly with the MOEE, for the remediation of well water contaminated by road salt. The Ministry also has a program to cover storage piles for road salt and salt/sand mixtures. Most salt piles are now covered. The Ministry monitors groundwater observation wells at patrol yards and picnic areas (with the help of MOEE).

4.6 Ministry of Health and the Public Health Units

The Ministry of Health through the Health Promotion and Protection Act can and has mandated monitoring programs for public drinking water supplies. In almost all cases the duty to carry out these monitoring programs is transferred to public health units. There are 43 public health units in the province. They are responsible to local boards of health (independent appointed bodies) or to regional governments. With few exceptions (Toronto is one) they are funded to 75% by the Ministry of Health and to 25% by the regional or municipal government.

The public health units conduct bacterial analysis of non-municipal public drinking water supplies (restaurants, hospitals and other institutions, trailer parks, camp sites, etc.) at intervals prescribed by the Ministry. The public health units have authority to demand improvements in public supplies such that safe drinking water is assured. Municipal water supplies are regulated under the OWRA by the MOEE but the health units often monitor these supplies.

The public health units will advise the MOEE and other agencies on the health significance of contaminants in wells and other drinking water or in groundwater that is to be used for drinking water (e.g. environmental assessments of planned new subdivisions). The Ministry of Health or the local public health unit also interprets these results for the public.

4.7 Ontario Clean Water Agency

The agency was established as a Crown Corporation in November 1993 to provide advice and services to municipalities for water and sewage systems on a fee for service basis. The following services are provided by the agency:

i) technical advice and services for water efficiency and demand management programs that ensure adequate supplies of water;
ii) evaluation of designs and project plans to ensure they meet required standards, protect the environment and accommodate future growth;
iii) facilitation of joint projects which allow several communities to share costs and manage area-wide growth; and
iv) administration of projects through planning, development and implementation stages.

The agency provides financial assistance by making direct investments which municipalities pay back over a specified period of time and it administers the Municipal Assistance Program (Ontario Ministry of Environment and Energy, 1993).

4.8 Ontario Waste Management Corporation (OWMC)

The Corporation was established under the Ontario Waste Management Corporation Act of 1981. It has been given a mandate to research, develop, establish, operate and maintain facilities for transmission, reception, collection, examination, storage, treatment and disposal of wastes, including sewage. OWMC will confine its attention to those industrial and hazardous wastes that cannot be handled by municipal sewage treatment plants, municipal incinerators or municipal landfills. The Corporation will not handle radioactive wastes or municipal garbage.

OWMC has identified three issues that it must address:

i) to design and build a waste treatment and disposal system for hazardous wastes not presently dealt with in Ontario;

ii) to assist industries in identifying additional practical ways to reduce and recycle their liquid/hazardous wastes; and

iii) to consult the public on the nature and scope of industrial waste problems and remedies.

The major activity of the Corporation since its creation has been the site selection (152 sites were initially considered), planning and preparation of the environmental assessment for a waste management facility proposed for the Township of West Lincoln in the Regional Municipality of Niagara. A draft environmental assessment for the proposed undertaking was submitted to the Ministry of the Environment in February 1988 (OWMC, 1988). In January 1989 a Joint Hearing Board was appointed under the Consolidated Hearing Act (OWMC, 1989). Hearings began in February 1990 and the projected date for final arguments before the Joint Board is Summer 1993.

4.9 Conservation Authorities

The conservation authorities are independent public corporations, established at the request of municipalities under the Conservation Authorities Act. The Ministry of Natural Resources coordinates their activities on a province-wide basis. They are given authority by law to conserve, restore and develop natural resources within a watershed. This involves not only water management, but conservation of land resources related to the watershed. Thus, in theory, they have some jurisdiction over groundwater in the watershed.

The conservation authorities may be concerned with the effects on groundwater from dewatering near dams or from gravel operations. They may also acquire wetlands and recharge areas whose management may affect groundwater and the overall water balance in the area. In the past, the authorities have not had comprehensive programs to manage groundwater. However, with increasing development pressures on watersheds, the authorities are conducting studies that include investigating groundwater flow systems. The Credit Valley Conservation Authority is conducting a watershed groundwater study which will consist of delineation of overburden and bedrock aquifers, natural groundwater quality, depths of static levels, recharge and discharge areas and other groundwater system parameters (Julie Parnaby, personal communication, 1992). The Grand River Conservation Authority is actively involved with the Water Resources Protection Strategy of the Regional Municipality of Waterloo (Golder Associates, 1992).

There are 38 conservation authorities in Ontario; the ones with the largest budgets and serving the largest population are the Metropolitan Toronto Regional and the Grand River Conservation Authorities. Some serving large areas are the Lower Thames Valley (8,257 km^2) Metagami Region (10,930 km^2), Nickel District (7,547 km^2) and the Grand River (6,804 km^2) Authorities.

4.10 Joint Institutions and Programs for the Management of Great Lakes Issues

Over the last few years the protection of groundwater and its potential effect on the water quality of the Great Lakes has become increasingly important for water management in the Great Lakes Basin (see also section 2.1). The government of Ontario and its officials are involved in several joint institutions for the management of Great Lakes issues. The lead agency in Ontario is, in most cases, the Ministry of Environment and Energy.

The institutions arise primarily from the Canada-United States Great Lakes Water Quality Agreement of 1978 (with the revised protocol of 1987) or from independent agreements of some or all of the parties involved with Great Lakes management.

4.10.1 Institutions Related to the Great Lakes Quality Agreement

4.10.1.1 Canada-Ontario Agreement Respecting Great Lakes Water Quality

The Canada-Ontario Agreement Respecting Great Lakes Water Quality (COA) establishes a mechanism by which the federal and provincial governments cooperate to implement the Great Lakes Water Quality Agreement. The principal institutions are the COA Board of Review, which oversees federal and provincial activities under the Agreement, and the COA Coordinating Committee which reports to the Board of Review. The Board of Review has representatives from three federal departments (Fisheries and Oceans, Environment Canada, Agriculture Canada) and three provincial ministries (Environment and Energy, Agriculture and Food, Natural Resources). Lead agencies are the federal and provincial departments of the environment.

The major initiatives under COA that may affect groundwater are:

i) the development of remedial action plans for the 17 areas of concern in Ontario;
ii) measures to deal with non-point sources of pollution;
iii) programs for nearshore surveillance and monitoring;
iv) the development of water quality objectives; and
v) the identification, characterization and control of groundwater contamination in the Great Lakes Basin.

Details of these programs are described in Government of Canada and Government of the Province of Ontario (1988).

As part of the Great Lakes Water Quality Agreement of 1978 as amended by the protocol of 1987 (Annex 16), it was decided to coordinate existing programs for the control of contaminated groundwater which could affect boundary waters including the Great Lakes. The following tasks were outlined in Annex 16:

i) potential and actual sources of groundwater contamination are to be identified;
ii) hydrogeologic conditions near existing and potential sources are to be mapped;
iii) a standard approach is to be developed for the assessment of contamination and the estimation of loadings from groundwater;
iv) sources are to be controlled; and
v) progress is to be reported biennially to the International Joint Commission (IJC).

4.10.1.2 Water Quality Board of the International Joint Commission

This Board is the principal advisor to the Commission. Its members are appointed by the Commission after consultation with the appropriate governments. They are instructed to serve on the basis of their professional expertise and not as representatives of their agencies. But they do provide an important linkage between the IJC and their respective agencies. The specific role of the Water Quality Board is discussed in Great Lakes Water Quality Board (1987) and in NRC and Royal Society of Canada (1985).

4.10.2 Other Programs and Institutions

Other programs and institutions dealing with Great Lakes management were originally created independently of the Great Lakes Water Quality Agreement but have generally been coordinated and often integrated into activities under the Agreement via COA and its institutions.

4.10.2.1 Niagara River Toxics Management Plan

This plan was developed jointly by Environment Canada, the Ontario Ministry of the Environment, the U.S. Environmental Protection Agency and the N.Y. State Department of Environmental Conservation. In February 1987, the heads of the four agencies signed a Declaration of Intent to accept the plan and to develop an extended plan for all of Lake Ontario.

4.10.2.2 Lake Ontario Toxics Management Plan

This plan, arising from the Declaration of Intent just mentioned, is coordinated by the Lake Ontario Toxics Committee. The plan was adopted by the agencies in February 1989 and follows the general principals of lakewide management plans required by Annex 2 of the 1987 protocol of the Great Lakes Water Quality Agreement (Government of Canada and Government of the Province of Ontario, 1988).

4.10.2.3 Upper Great Lakes Connecting Channels Study

In 1984, a cooperative study was undertaken to assess toxics in the Upper Great Lakes Connecting Channels, i.e. in the St. Mary's River, St. Clair River, Lake St. Clair and Detroit River. The principal participants were eleven federal, provincial and state agencies on both sides of the Canada-U.S. border. In Canada, these were the federal departments of Environment and of Fisheries and Oceans, and the Ontario ministries of Environment and Energy and of Natural Resources. The study was coordinated through a management committee and an activities integration committee with representatives from all the major agencies. The committees are about to be dissolved and their work is to be taken up by three separate remedial action plans and RAP work teams (for the St. Mary's, St. Clair and Detroit Rivers).

4.10.2.4 Soil and Water Environmental Enhancement Program

This program is based on a Canada-Ontario agreement of May 1986 between the federal departments of Environment and of Agriculture and the Ontario ministries of Environment and of Agriculture and Food. The program is coordinated by a management committee consisting of these four agencies and, reporting to it, a federal-provincial working committee. The primary aim is to reduce phosphorus loadings to the Great Lakes. The program also develops and promotes soil and water conservation. The program is closely tied to the "Ontario Soil Conservation and Environmental Protection Assistance Program", "Tillage 2000" and the "Land Stewardship Program" operated by the Ministry of Agriculture and Food (see section 5.4 and Government of Canada and Government of the Province of Ontario, 1988).

4.11 Other Agencies

In addition to these provincial agencies, there are other federal agencies and provincial or federal Crown agencies that have a role to play in Ontario. The most important provincial Crown agency is Ontario Hydro, which has extensive systems and programs to prevent (among others) groundwater contamination by nuclear waste and coal and coal ash at its nuclear and coal-fired power plants.

The most important federal Crown agency in Ontario is Atomic Energy of Canada Ltd. It is responsible for a nuclear fuel preparation facility and a nuclear research station. Other federal agencies include the Atomic Energy Control Board with its jurisdiction over all of the nuclear fuel cycle; and Environment Canada and Agriculture Canada, both of which are involved in various groundwater monitoring programs in the province (usually in cooperation with provincial agencies). Finally there is the International Joint Commission with headquarters in Windsor, which together with federal, provincial and state governments on both sides of the border, is responsible for all matters affecting boundary waters.

5.0 Other Instruments of Groundwater Management

5.1 Monitoring

5.1.1 Water Level Monitoring

Ontario did have a water level monitoring network that covered the whole province. Data from this network were stored on computer until 1981 and on paper file until 1984. Since then it has been left to the regions whether or not to continue water level monitoring. The Southwestern Region monitors at 16 observation wells, the Central Region at 28; all monitoring is done with automatic recorders. The other regional offices do not conduct water level monitoring.

Water level monitoring is required around large withdrawal wells as a condition for the Permit to Take Water. Although wells are usually installed by the municipalities, the regional offices of the MOEE will monitor the wells in many cases.

5.1.2 Water Quality Monitoring

A program to monitor the base quality of groundwater does not exist. However, regular monitoring of many municipal, other public and private drinking water supplies, some of which are fed by groundwater, is required. All other monitoring is done for specific purposes. Routine monitoring programs are the following:

i) The Drinking Water Surveillance Program (DWSP) is a program to monitor municipal water supplies. Beginning in 1986, it has been operated by the Drinking Water Section of the MOEE. At present (1993), 120 municipal water supplies (22 of them groundwater fed and 6 mixed supplies) are monitored for over 180 parameters. The parameters being monitored are biological, inorganic and other standard water parameters, metals, organics (chloroaromatics, chlorophenols, pesticides, PCBs, phenolics, polyaromatic hydrocarbons and volatiles) and radionuclides. There are 61 pesticides being monitored. The short-term goal is to monitor 180 supplies and it is hoped that eventually all 466 municipal supplies (271 are on groundwater and 195 surface water) can be covered by this program. Raw, treated and distributed water is being sampled and analyzed and extensive quality control is being applied for sampling and analysis. Data are stored on a computerized database.

ii) The public health units monitor all non-municipal public water supplies (restaurants, hospitals and other institutions, trailer parks, camp sites) from two to six times a year for bacteriological contamination. The health units also provide a monitoring role for private water supplies in respect to both bacteriological and chemical quality.

iii) Groundwater monitoring is usually required at potential and actual sources of groundwater contamination. Thus monitoring occurs at most landfill sites, mine sites, radioactive waste deposits and sites where contamination has occurred. Such monitoring is usually the responsibility of the person or agency responsible for the site and is supervised by the regional office of the MOEE.

Some special-purpose monitoring programs are the following:

i) Agriculture Canada has had a program since 1987 to monitor pesticides in drinking water across Canada. In 1987, 80 municipal supplies in Ontario were monitored for phenoxyaliphatic acids (2,4-D, 2,4-DB, diclofop-methyl, MCPA and picloram). In 1988 farm wells were measured, 25 were measured for triazines, 15 for carbamates, 30 for organophosphates and 10 for triallate and trifluralin. Agriculture Canada, along with seven other agencies, conducted the Ontario Farm Groundwater Quality Survey which is described in section 2.8.2.

ii) The Drinking Water Section of the MOEE has been monitoring for pesticides and nitrates in groundwater in sensitive areas. They have monitored and are still monitoring for aldicarb (Alliston area) and triazines (Strathroy area). In addition, domestic wells in corn growing areas have been monitored for triazines and other selected pesticide groups including organophosphates, acetanilides and phenyl ureas. In 1984 and 1985 selected private wells were sampled for alachlor as part of an extensive monitoring program for alachlor. Since 1986, nitrate and bacteriological contamination have been measured at the same time as pesticides.

iii) The Agricultural Laboratory Services Branch of the Ministry of Agriculture and Food has sampled a large number of farm wells (596 wells between 1969 and 1984) for a wide range of pesticides. Wells were sampled when contamination was suspected or was known to have occurred and pesticide handling practices around the well were investigated and recorded. In practically all cases, the contamination had occurred because of poor handling practices (spills, backflow directly into the well, etc.).

iv) There are also a few other special-purpose monitoring programs worth mentioning:
a) The National Water Research Institute (NWRI) of Environment Canada is investigating the regional hydrogeology in the Niagara Falls area using seven (up to 150 m deep) boreholes. A similar study by the U.S. Geological Survey is underway on the U.S side of the border. The study is important for understanding the extensive contamination of ground and surface water in the area.
b) A deep (300 m) borehole with multiple measuring ports has been drilled in the Sarnia area under the supervision of the MOEE and NWRI. The purpose of this hole is to monitor and characterize the deep hydrogeology in the area after the deep-well disposal of the 1960's and early 1970's.
c) At the AECL research laboratory at Chalk River there is an extensive monitoring network to characterize and understand the transport of radioactive contaminants in groundwater. Such contamination has occurred in the 1950's and 1960's.

5.2 Groundwater Mapping and Aquifer Resource Evaluation

5.2.1 Groundwater Probability Maps

These maps were produced largely by the Ontario Water Resources Commission and the MOEE between 1970 and 1986. Fourteen maps covering eleven counties and two regional municipalities in southern Ontario were prepared. The maps show aquifers in bedrock and in overburden, depth to water, well yields in both types of aquifer, flow patterns and some water quality data (up to 25 parameters).

5.2.2 Water Resources Reports

These reports provide information on surface water and groundwater in various drainage basins. Twenty-two reports were published between 1969 and 1982. They contain information on geology, thickness of the overburden, groundwater potential and yields, hydrological budgets, hydrochemistry and streamflow.

5.2.3 Water Resources Bulletins

These are water well records and data from the observation well network in published form. The last published water well records are from 1981, the last published data from observation wells are from 1980.

5.2.4 Major Aquifers in Ontario Map Series

Eight maps provide information on major aquifers in southern Ontario. The maps provide information on the geology of the aquifer, depth to water, expected yields and the areal extent. The largest area is covered by two maps for the whole Lake Ontario Drainage Basin, one for bedrock, the other for overburden. Others describe the Guelph-Amabel and the Guelph-Lockport aquifers, the Alliston aquifer complex and the Oak Ridges aquifer complex.

5.3 Data Collection and Databases

5.3.1 Drinking Water Surveillance Program

Data from monitoring of municipal water supplies are collected on a database and are accessible to all offices of the MOEE. The database contains information on the facility and the distribution system, process parameters including field sampling procedures, emergency contacts for the specific system (Medical Officer of Health, Ministry contacts, etc.), sampling and analytical data, and basic chemical and toxicological data for different compounds including different water quality objectives and guidelines. It is meant to provide (Hunsinger et al., 1987):

i) immediate,reliable easily accessible information;
ii) flags where water quality objectives are exceeded;
iii) contaminant levels and trends;
iv) comprehensive database for remedial action;
v) framework for assessment of new contaminants; and
vi) indication of treatment efficiency of plant processes.

5.3.2 Water Well Records

Water well records have to be submitted by drillers to the MOEE. Inspectors from the regional offices determine the UTM coordinates of the well and forward a copy to the Environmental Monitoring and Reporting Branch. Until 1984 these records were kept in summary form on a computerized database and periodically published as Water Resources Bulletins for the various regions. Records for approximately 300,000 wells are available on the database. Since 1984 well logs (approximately 15,000 wells are recorded each year) have not been systematically filed on a computer database at headquarters or in any of the regional offices. In most regional offices there may be delays up to one year before UTM coordinates are recorded.

5.3.3 Petroleum Resources Data System

The Ministry of Natural Resources maintains a database of wells over which the Ministry has jurisdiction (oil and gas wells, brine caverns, deep-well disposal). Each record contains information on the lithology, E-logs and hydraulic heads for selected formations in the well. Records are available for about 40,000 wells. About 13,000 are computerized, along with production data and Crown land leases and licensing data, on the Petroleum Resources Data System kept at the Petroleum Resources Centre in London.

5.3.4 Data on Boreholes from Mineral Exploration in Overburden

The Ontario Geological Survey of the Ministry of Northern Development and Mines has collected stratigraphic and geochemical data from boreholes in overburden in some areas of the province. This was done under the Reconnaissance Till Sampling Program. Most of the holes were drilled by a sonic borehole technique to assist in mineral exploration. They are between 2.7 and 148.4 m deep with an average depth of 36.5 m.

Graphic logs including descriptions of mineral composition and texture and geochemistry of the various size fractions are available. Interpretive notes on stratigraphy and glacial history are included for some of the areas. Some of the data are published and are available on a separate sheet for each hole. Data have been collected for the Black River/Matheson area (225 holes, published), Fort Francis area (71 holes, to be published), Kirkland Lake area (171 holes done by reverse circulation technique, not published), and Chatham/Windsor area (about 25 holes, not published).

5.3.5 Occurrence Report Information System

Following enactment of Part X of the Environmental Protection Act, all spills have to be reported to the MOEE. The Spills Action Centre receives approximately 5,000 reports a year and enters them in the Occurrence Report Information System (ORIS). ORIS is a computerized database management system that is accessible to all of the Ministry's offices. Spill information is accessible to the offices but can only be input by the Spills Action Centre.

All complaints and violations under the jurisdiction of the Ministry and all other pollution incidents that field personnel have to investigate are entered on standard forms and became part of ORIS. The database contains cases of enforcement, contact with the public, notifications of non-compliance and control and stop orders. Of the 15,800 occurrences entered in ORIS in 1991, about two-thirds were complaints and violations and about one-third was reported spills (Ontario Ministry of the Environment, 1992a).

The number and types of complaints related to groundwater and the type of follow-up action may be obtained from this database.

5.3.6 Regional Databases

In some regions, the Technical Support Section has developed databases for its own use to track complaints, investigations and approvals related to groundwater. The most elaborate is found in the Southeast Region (Kingston). A "Groundwater Works Information System" records all field activities such as investigations into complaints, interference of water supplies, site assessments, etc. An "Office Works Information System" keeps track of approvals, applications for approvals and hydrogeologic reports for subdivisions, site decommissionings and planning activities. Both databases feed into the "Program Information Management System" which keeps track of all approvals and complaints for surface water, groundwater and air. All three databases reside on personal computers.

5.4 Technical Assistance

The following services are provided:

i) In the case of supply problems or groundwater quality problems, the district office of the MOEE or the public health units will investigate and in certain cases provide a solution.

ii) If a spill occurs, the Spills Action Centre of the MOEE operates a 24 hour toll-free number. The Centre will refer calls to private contractors and to district offices of the MOEE for cleanup.

iii) Bacterial analysis of private (and public) wells, interpretation of results and advice for disinfection of wells is provided free of charge by the local or regional health units.

iv) Routine chemical analysis must be paid for by a well owner. If the district or regional office of the MOEE decides that there is a reasonable suspicion of contamination of a well, sampling and analysis may be carried out by the Ministry or the owner may be compensated.

v) Non-municipal public water supplies (restaurants, schools, summer recreational camps) are monitored by the local health units during routine public health inspections.

vi) Private septic systems are inspected by the local or regional health units (with cost recovered from the MOEE) or by contractors to the MOEE. Private water wells are inspected by inspectors from the MOEE; underground fuel tanks are inspected by inspectors from the Ministry of Consumer and Corporate Relations or by municipal or regional inspectors. In all cases some limited technical advice may be given. However, not all storage tanks or wells will undergo a thorough inspection.

vii) The Ministry of Agriculture and Food (OMAF) has several technical and financial support programs for soil conservation, pesticide use and manure and fertilizer management. These programs have an impact on groundwater protection. The most important of these programs are:

a) the Agricultural Extension Program (collaboration between OMAF personnel and farmers) on conservation matters and good farming practices;

b) the Ontario Soil Conservation and Environmental Protection Program (financial and technical assistance to farmers to control erosion, manure, pesticides, etc.);

c) the Land Stewardship Program (financial and technical assistance to farmers to engage in soil conservation);

d) Tillage 2000 (applied research program on soil conservation); and

e) Food Systems 2002 (a program to reduce pesticide use by 50 % within the next 15 years; within the program research funds are available for development of alternatives to pesticides).

viii) Several agencies such as the Ministry of Agriculture and Food, Ministry of Environment and Energy, AGCare and other agricultural organizations have developed and implemented initiatives to improve the environmental quality of Ontario's farms. With respect to groundwater quality, relevant programs include the Ontario Farm Environmental Review. The review aids farmers in assessing the environmental risk of some practices and conditions on their farms. The risk of groundwater contamination is assessed by examining parameters such as location and condition of a well and the proper storage and handling of pesticides (Ontario Farm Environmental Coalition, 1992).

ix) The Ontario Waste Agricultural Pesticides Collection Program has been successful in safely disposing of deregistered, unwanted, or otherwise unuseable agricultural pesticides. The Pesticide Container Recycling Program was setup to collect clean pesticide containers which in the past have been burned on the farm since most municipal landfill sites would not accept them (AGCare, 1992a,b).

5.5 The Municipal Assistance Program

This program is administered by the Ontario Clean Water Agency (OCWA). It provides financial assistance for the construction of communal water and sewer systems, and in specific cases for the repair or upgrading of private wells and sewage disposal systems.

i) All communities are eligible for basic assistance of 15% of the cost of the major components of water and sewer works. Costs of related engineering reports are also eligible.

ii) For communities with less than 15,000 inhabitants, basic assistance of 70% of the total cost of water or sewer works may be available. For communities between 15,000 and 200,000 inhabitants, a sliding scale of 70% to 0% applies. The exact percentage depends upon the population, i.e. it decreases with increasing population. Small communities within a larger regional municipality are eligible, provided the regional municipality also contributes.

iii) Individual home owners in small communities may be eligible for up to 85% of the cost for renewal or replacement of faulty wells or septic systems.

iv) At the request of a small municipality, a project funded under this program, may be managed by OCWA on a fee per service basis.

v) Regular or special category loans are available for: rehabilitation of water and/or sewage systems; environmental study reports; and studies of private systems, water efficiency and system optimization.

In addition, other financial assistance programs with an impact on groundwater management are available mainly to farmers. They have been outlined above in the assistance programs available from the Ministry and Agriculture and Food (section 5.4).

5.6 Information

The most complete piece of information on groundwater for the general public is a publication by the MOEE, "Water Wells and Groundwater Supplies in Ontario" (1987). This publication contains basic information on planning for groundwater supplies, on water wells, well construction, well problems, pumps, quality problems, water treatment, water well legislation, etc. In addition it gives a list of available maps, reports and other publications on groundwater management and use. Some of them are listed below.

i) "Water Management - Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment" (1978, revised 1984). This publication, also called the "Blue Book" describes the overall policy of the Ministry.

ii) "Water Resources of Ontario" (1986). This publication by the Ministry of Natural Resources on surface and groundwater resources provides a good general description of groundwater resources and their interaction with surface water; both bedrock and surficial groundwater are discussed.

iii) "Cottage Country; An Environmental Manual For The Cottager". Ministry of the Environment (fourth edition 1986).

iv) Fact sheets by the Ministry of Environment and Energy:
"Protection of Water Quality in Drilled Wells" (1986);
"Protection of Water Quality in Bored and Dug Wells" (1986);
"Recommended Methods for Plugging Abandoned Water Wells" (1986);
"Information on the Use of Home Water Treatment Devices" (1986);
"About Septic Tanks" (1985);
"Water Fit to Drink" (1986).

v) The Ontario Drinking Water Objectives (revised 1983). They are also listed in the "Blue Book" described under (i) above.

vi) The Ontario Ministry of Agriculture and Food has produced publications on application and handling of pesticides and fertilizer, manure management, drainage and other topics that influence groundwater quality. Some titles are "Field Crop Recommendations", "Guide to Chemical Weed Control", "Survey of Pesticide Use in Ontario" and "Agricultural Code of Practice". A complete list of these publications is available from the Ministry.

5.7 Waste Management

When waste has been improperly stored or disposed of, groundwater can be the first medium threatened. Contaminated groundwater then becomes the prime route for contamination of surface waters. Thus many aspects of waste management affect groundwater, either directly, because wastes contaminate groundwater, or indirectly, because reduction or improved management of these wastes lessens the chances of contamination.

Ontario began to revise its waste management policy in 1982-1983 (Glenn and Orchard, 1986). The general direction of the waste management plan was presented in the "Blueprint for Waste Management in Ontario" which stressed the importance of reduction, re-use, recycling and recovery for industrial, residential and special wastes. The "Blueprint" also outlined proposals for:

i) classification of wastes;

ii) the authority and responsibilities of various levels of government;

iii) area waste management planning;

iv) the role of hearings, approvals and appeals; and

v) the necessity of perpetual care of waste.

In legislation enacted since then (mainly Regulation 347, see section 3.3.1.5), control and accountability is required at all stages of waste management. The main tool for such uninterrupted control of hazardous wastes is the "generator registration reporting" system. In addition, wastes and sites for storage, disposal and management of wastes are classified in Regulation 347. Legal requirements for the management and closure of the various sites are explicitly stated in Regulation 347.

Other important aspects of the waste management system are described in the following sections.

5.7.1 IWA Landfill Site Selection Process

The Waste Management Act, 1992 established the Interim Waste Authority Limited (IWA) as a provincial Crown agency responsible for the selection of three long term landfill sites within the regional municipalities of Peel, Durham and Metropolitan Toronto (IWA, 1992b). The site selection process used by the IWA is based on the requirements of the Environmental Protection Act and the Environmental Assessment Act

In the screening to identify suitable geographic areas, geology/hydrology is a criterion along with agriculture, biology and land use. The objective of the hydrogeological criterion is to protect all uses of groundwater including all major aquifers and drinking water sourses. Areas of "complex geology", defined as areas of ice contact drift and associated hummocky topography, are screened out. For the Greater Toronto area, the Oak Ridges Moraine was immediately removed as a potential area (IWA, 1992b).

Once the candidate area is identified a list of potential sites in the area is prepared. Sites on the initial list are compared and evaluated using existing data and information to prepare a long list of candidates sites. Indicators used to assess hydrogeology include the ability of the site to provide natural protection from leachate, predictability of groundwater pathways and disruption to groundwater supplies and resources (IWA, 1992b).

To develope the short list of candidate sites the criteria and indicators are then ranked and weighted providing a more quantitative assessment of the sites. The highest ranking and greatest weighting is given to the geology/hydrogeology of the site (IWA, 1992c). Finally, field studies are conducted at the short list sites to select the preferred site. The groundwater field studies supply information on stratigraphy, hydraulic conductivity, grain size of sediments and groundwater geochemistry. This information is used in a groundwater flow model to predict concentrations of critical groundwater quality parameters at the boundaries of the sites (IWA, 1992a).

5.7.2 Ontario Guidelines on Application of Sewage Sludge

In addition to criteria to prevent metals concentrating in soils to toxic levels, guidelines for the application of sewage sludge to agricultural land include measures for groundwater protection. The guidelines specify that the groundwater level must be 0.9 m below grade and the bedrock must be 1.5 m below grade. A minimum distance of 15 m is required between spreading sites and drilled water wells that are greater than 15 m deep. For all other wells, including dug wells, the distance is 90 m (Ontario Ministry of Agriculture and Food and Ministry of the Environment, 1992a, 1992b).

5.7.3 Waste Disposal Site Inventory

The provincial government created a $100 million environmental protection fund to finance waste site investigations and cleanups and in 1985 a $20 million security account was set up to rectify environmentally hazardous situations (Glenn and Orchard, 1986). The MOEE now has a long-term comprehensive program in place to investigate and monitor waste disposal sites throughout the province. The information sources include the Ministry's computerized data files on individual sites, file archives and field inspection reports of the sites.

5.7.4 Ontario Waste Management Corporation (OWMC)

A preferred location for OWMC's hazardous waste management facility has been selected. It is located in West Lincoln Township in the Regional Municipality of Niagara. That site and the planned facility for that site are undergoing full environmental assessment which includes extensive public hearings (see sections 3.3.3 and 4.8). The final environmental assessment documents were submitted to the MOEE in November 1988 and public hearings are expected to be completed during Summer 1993.

The proposed facility will contain the following:

i) a high temperature rotary kiln incinerator for incineration of liquids, solids, and sludges;

ii) physical-chemical treatment plant for waste solidification/stabilization; and
iii) an engineered landfill for the disposal of solid residues from the other treatment operations.

The landfill will be operated in a continuous mode and will be located over a deep layer of uniform, finely textured clay. A system of monitoring wells will allow observation of groundwater quality during the operational and post-closure phases.

5.7.5 Regional Waste Management Master Plans

The MOEE encourages regional municipalities to develop long-term (25 year) regional waste management master plans. The plans are developed by steering committees and task forces that include municipal, regional and provincial officials, as well as elected representatives, private citizens and representatives of non-government organizations. In some cases (e.g. Ottawa-Carleton) federal officials are also involved. The MOEE funds up to 50 % of the cost of the development of the plans under the Master Plan Program. In the plans, waste disposal and all methods for waste reduction, re-use, recycling and recovery are considered simultaneously (e.g. energy from waste, recycling, composting, source separation, etc.). The plans form the basis of the environmental assessment documents required for approval of any waste management facility.

5.7.6 Waste Reduction and Recycling.

Starting from a number of pilot projects (e.g. the Waterloo Waste Reduction and Recycling Advisory Committee), Ontario has developed a comprehensive program for waste reduction and recycling. This program is based on the four stated goals to reduce, re-use, recycle and recover waste and is targeted towards industrial and hazardous as well as municipal waste. By October 1992, landfill waste had been reduced by 21 % of 1987 levels.

In addition to the blue box program, other key elements of the waste reduction plan include composting and encouraging diversion of industrial, commercial and institutional wastes. The programs for the reduction of industrial and hazardous waste are conducted by the OWMC and the MOEE, in collaboration with the Association of Municipal Recycling Coordinators. A small part of this effort is the Ontario Waste Exchange, a program operated by ORTECH International (previously Ontario Research Foundation) and funded jointly by OWMC and MOEE.

Apart from the waste exchange (see Glenn and Orchard, 1986) the waste reduction program provides assistance to industry to reduce, re-use, recycle, recover and as a last resort to dispose of the waste. The assistance takes the form of advice by specialists, waste audits and other plant visits, as well as workshops, manuals and newsletters. Recommendations may be made for small research projects which OWMC may choose to conduct. Under the Industrial Waste Diversion Program the MOEE will also provide grants to industry up to 100 % for research and up to 50 % for capital equipment for projects to recycle, re-use, reduce or recover waste, usually hazardous waste, from the industrial, commercial and institutional sectors.

The program for the reduction of household waste is conducted by the MOEE together with regional and local municipalities and is preferably tied into the regional waste management master plans. As part of this:

i) the blue box program for recycling of newspaper, glass, tin cans and some plastics has expanded to 3.2 million households;
ii) the blue box program has been extended to schools (STARS program);
iii) the Waste Reduction Information Service has been established to assist in recycling, re-use, etc;
iv) technical assistance (including on-site inspection) is given to municipalities, institutions and commercial establishments to help them with their waste problems; and
v) various regulations, standards and government purchasing policies are developed and implemented to reduce packaging, decrease the amount of non-recyclable material, and encourage increased recycling, re-use and recovery.

5.7.7 Other Financial Assistance for Improved Municipal and Industrial Waste Management

Aside from the assistance connected to the programs just mentioned, the MOEE also has:

i) the Funding Assistance Program (FAP), managed by the Waste Reduction Office, under which up to 75 % of the capital cost of new or expanded municipal waste processing facilities, transfer stations or landfills may be paid;
ii) the Waste Management Improvement Program, also managed by the Waste Reduction Office, under which up to 75 % of

the total cost for the improvement of and remediation at existing municipal waste disposal sites may be paid; and

iii) the Household Hazardous Waste Program, managed by the Program Development Branch, under which up to $15,000.00 can be provided to a municipality to hold "toxic roundups" when residents bring household hazardous waste to a depot for proper disposal.

5.7.8 Municipal Industrial Strategy for Abatement (MISA)

The MOEE has engaged in a major program to characterize industrial and municipal discharges to surface waters and to control such discharges at the source. While the program is directed exclusively toward the protection of surface waters, the scale of the program and the reduction of effluents that are planned is likely to have a positive effect on groundwater contamination.

5.8 Planning and Groundwater Quality Protection

5.8.1 Background

A huge scientific and technical effort has been expended to devise methods to clean up contaminated aquifers to drinking water standards. However, experiences with groundwater remediation have shown that producing drinking water from contaminated aquifers is very difficult, if not impossible, as well as being very costly. The best that available technology can do is to contain the contamination (Bredehoeft, 1992).

Rather than relying on the expensive cleanup of aquifers after they are contaminated, many jurisdictions are implementing groundwater protection strategies whose objective is to prevent groundwater contamination. These strategies integrate urban and rural planning with hydrogeological information to prevent high risk land uses on sensitive areas such as recharge zones and areas around communal well heads. High risk land uses that could lead to groundwater contamination include industrial activity, storage facilities of potential contaminants, aggregate extraction, solid waste disposal, high density septic tanks and other concerns identified and discussed in the second chapter of this report.

In addition to land use restrictions, appropriate design requirements for potentially polluting facilities also form an integral part of groundwater quality protection. Some examples of design requirements are secondary containment for underground storage tanks, properly cased and grouted water wells, more effective on site sewage treatment and groundwater monitoring to ensure that the systems work (Cherry, 1989). Land use restrictions and proper design of facilities can be integrated into municipal plans.

5.8.2 Regional Groundwater Quality Protection Plans

Although Ontario has various laws and policies that relate to groundwater protection, it has not moved towards protection in a substantial manner (Cherry, 1989). Due to the lack of a comprehensive provincial strategy, some regional municipalities and townships are designing and implementing their own groundwater protection strategies. Although the OWRA gives the MOEE responsibility for groundwater, the Planning Act assigns responsibility to local government to ensure the health and safety of inhabitants (Geo-Analysis Inc and Richards and Associates, 1992).

5.8.2.1 Regional Municipality of Waterloo

The Regional Municipality of Waterloo (RMOW) is developing and implementing an eight stage water resources protection strategy. The water supply for the RMOW is provided by an integrated system of approximately 126 municipal groundwater wells, numerous communal, industrial and private wells and surface water withdrawal from the Grand River. Water quality monitoring of the Grand River shows that surface water quality is generally satisfactory for drinking water supplies. Groundwater quality in the RMOW is threatened by non-point sources from agricultural activities and point source industrial contamination.

The objective of the protection strategy is to minimize the threat from existing sources of contamination and prevent new sources of contamination from occurring. The first stage of the strategy is to characterize and understand the quality, extent, distribution and annual rate of renewal of the groundwater resource. This information is needed to sustainably manage the resource and to delineate areas that are sensitive to contamination. The second stage is to identify and evaluate existing and new sources of contamination and limit their impact on groundwater. New sources of contamination will be subject to appropriate policies to protect sensitive areas.

The acquisition and management of data on water quality and hydrogeology comprise the third and fourth stages. The monitoring network for both surface and groundwater will be maintained through close coordination of the RMOW, the MOEE and the Grand River Conservation Authority. Computerized database management systems and geographic information systems are being developed to ensure that the data are accessible to the greatest range of users and are continually updated.

The degradation of water quality by stormwater and urban runoff will be addressed by developing management guidelines and appropriate planning based on integrated watershed management. This approach, the fifth stage of the strategy, will serve to proactively protect the many small urban watersheds in the RMOW.

The final three stages of the strategy involve the identification of a set of existing policies and legislation for water resources protection, integrating water related emergency response into the existing emergency planning network, and involving the community in strategic planning and implementation (Golder Associates, 1992).

5.8.2.2 Regional Municipality of Ottawa-Carleton

The Regional Municipality of Ottawa-Carleton (RMOC) commissioned a comprehensive study of the impacts of private wells and septic systems on groundwater (Geo-Analysis Inc and Richards and Associates, 1992). The objective of the study was to compile existing physiographic and hydrogeologic information into a single database which was used to construct an aquifer management system using a geographic information system (GIS). The GIS could outline areas where development of private services should be encouraged and areas where it should be discouraged. The goal was to provide planning criteria to ensure sustainable development of private individual services.

The study identifies groundwater problems in the RMOC and makes several observations and recommendations on a variety of groundwater issues. The recommendations include implementation of well head protection measures, a moratorium on the use of groundwater heat pumps, proactive inspection of the construction of water wells, more and better hydrogeologic information from developers, more sophisticated methods of determining lot sizes for septic systems and more stringent requirements for septic systems.

A main focus of the study was the use of septic systems. The impact from septic systems depends on site-specific conditions such as the soil permeability and the density of development. It was recommended that site-specific soil conditions and hydrogeology be taken into account in planning sustainable development of individual services. To achieve this three conditions that should be investigated include:

i) ability of overburden to transmit sewage effluent;
ii) ability of underlying materials to protect the aquifer; and
iii) ability of hydrogeologic systems to ensure acceptable cumulative impact.

It was also recomended that the leaching bed should be covered by at least 1.2 m of unsaturated soil; lot size on impermeable soils should be determined by hydraulic mounding calculations; and lot size on permeable soils should be determined by the flowthrough method using mathematical models that simulate nitrate transport (Geo-Analysis Inc and Richards and Associates, 1992).

5.8.2.3 Township of Kingston

The Township of Kingston, which extends north and west of the City of Kingston, commissioned a study to characterize the hydrogeology and to determine if adequate groundwater resources exist for present and future development using private individual services. Similar to the Ottawa-Carleton study, the goal was to provide planning criteria for developments using septic systems and supplied by groundwater (Golder Associates, 1990).

Using existing information, a survey of local residents and discussions with water well contractors, general trends in groundwater availability and quality were characterized. The major source of groundwater is a fractured limestone aquifer in the Gull River Formation. Since the aquifer is covered by a thin layer of soil, the groundwater is susceptible to contamination from sources such as septic systems, surface runoff and agricultural/industrial activities. Adequate quantities of good quality water for communal supplies are generally not available in the township.

Recommendations for the design and construction of private individual services were based on terrain types. The terrains identified were shallow rock, granular overburden, fine-grained overburden (clay and silty clay) and organic deposits and alluvium. For each terrain detailed recommendations and guidelines were given for the design and construction of water wells and septic systems. However, since conditions can vary within the terrains, site-specific hydrogeologic information should be required to ensure appropriate design and construction specifications.

Other recommendations included the following: a minimum lot size of 0.8 ha; the water supply demands and waste characteristics of a proposed industrial development should require a detailed hydrogeological investigation; and a certification program should be implemented to ensure that the construction of water wells complies with existing regulations or with more stringent requirements if considered necessary to protect the groundwater resources (Golder Associates, 1990).

5.8.2.4 Region of Peel

The Region of Peel has initiated a well head protection program whose main objective is to protect the recharge areas of municipal wells. In addition to conducting public meetings to construct the framework of the program, existing information from well records and reports is being compiled to identify areas where hydrogeological data are required. Once the information is acquired it will be used in a numerical groundwater flow model which will identify and delineate the recharge areas to be protected (John Savage, personal communication, 1992).

5.8.2.5 Region of York

The Region of York has experienced intense development and a requisite increase in water demands during the 1980's. Between 1981 and 1989 the average production from municipal wells extracting groundwater from a lower confined aquifer increased from 22,600 to 38,500 m^3/day. The communities of Oak Ridges, Aurora, Newmarket, Holland Landing, Sharon-Queensville and Bradford are entirely dependent on water supplies from the lower aquifer (Kuehl et al., 1992). The region's main concern has been the quantity of groundwater rather than its quality.

To assist with development planning the region commissioned a study to determine the maximum sustainable yield of the lower aquifer. Using existing information and a numerical groundwater flow model it was found that the maximum yield of the lower aquifer is about 50,000 to 55,000 m^3/day, with a capability to provide peak production of 82,000 m^3/day for 90 days or 88,000 m^3/day for 30 days (Kuehl et al., 1992). As a result of the study an aquifer management plan for Aurora, Newmarket and East Gwillimbury has been designed and approved (Bruce MacGregor, personal communication, 1993).

5.8.2.6 Oak Ridges Moraine of the Greater Toronto Area

North of Metropolitan Toronto, the Oak Ridges Moraine (ORM) is a prominent landform consisting of a 200 km long ridge running in the east-west direction. As well as a significant natural area, the moraine is a watershed divide and a major recharge area. It provides headwaters for many rivers and streams and in contrast to the areas to the north and south, it has 30% natural cover. As a result of the recommendations of the report "Space for All: Options for a Greater Toronto Area Greenlands Strategy", the provincial government expressed its interest in the long term protection and management of the moraine.

A two year planning study is being conducted to provide the information required to develop a long term protection strategy for the ORM. In the meantime the province will work with municipalities in the Greater Toronto area to ensure that inappropriate development does not occur before the long term protection strategy is implemented. The provincial agencies include the Ministries of Natural Resources, Environment and Energy, Municipal Affairs and the conservation authorities.

To evaluate the potential environmental impacts of proposed developments, a set of eight principles has been identified. The principles are very similar to environmental components used in environmental assessment and include growth and settlement, ecological integrity, landform conservation, significant natural areas, woodlands, watercourses and lakes, highly permeable soils and groundwater resources.

The last two principles of highly permeable soils and groundwater resources are directly related to groundwater protection. Development on highly permeable soils will not be permitted until a groundwater management strategy has been developed. This is to ensure the protection and maintenance of the recharge capacity and water quality of aquifer systems in the area.

Any proposed development must ensure that significant interference with water use on neighbouring areas does not occur. To minimize adverse impacts to groundwater quality, the development plan must include appropriate construction, design and landscape measures. Stormwater must not degrade groundwater quality and measures must be in place to ensure that fish or their habitat are not negatively affected.

The evaluation and review process will apply to official plans and amendments, zoning by-laws and amendments, plans of subdivisions and severences for all land uses including, but not limited to, residential and estate residential, golf courses, commercial and industrial operations (Ontario Ministry of Natural Resources, 1991).

5.8.3 MOEE Interim Planning Guidelines

To inform municipalities and consultants of the requirements of the MOEE and to assist in the review of planning documents, the MOEE has released seven interim guidelines. The guidelines are implemented through comments and advice supplied by MOEE staff to municipalities, the public and approval authorities (approval authorities are designated under the Planning Act). The guidelines deal with sewage and water services, the re-use of contaminated sites and technical requirements for pre-development groundwater assessments. The last category is the subject of two technical guidelines that relate to private water wells and septic systems.

5.8.3.1 Technical Guideline for Assessing the Potential for Groundwater Impact at Developments Serviced by Individual Sub-Surface Sewage Systems in Non-Designated Areas

The first objective of this guideline is to provide the technical guidance for consultants to assess the impact of septic systems on groundwater quality in new developments. The second objective is to provide the MOEE Director with the hydrogeological information needed to make a decision on whether a development should proceed. The goal of the guideline is to ensure that the quality of groundwater is protected from the potential adverse impacts of septic systems, specifically nitrate contamination.

The guideline applies to subdivision plans of more than five units using septic systems. The guideline does not apply to those areas that have been designated by a MOEE Director under the Reasonable Use Policy. For designated areas the impact assessment outlined in the Reasonable Use Policy is applicable. Since very few areas have been designated, the interim guideline applies to most of Ontario. It also does not apply to large subsurface disposal systems, defined as having average flows greater than 4,500 L/day, or to isolated residential units.

The three step assessment process outlined by the guideline consists of the following:

i) lot size determination;
ii) evaluation of hydrogeology to determine if potential exists for contamination of groundwater by septic systems; and
iii) detailed evaluation of contaminant loadings.

All three steps may not be required if it can be shown in the initial steps that potential for contamination does not exist. If the proposed lot size is 1 ha or greater, then the MOEE considers the lot large enough for dilution to reduce the concentration of nitrate to acceptable levels and the second and third steps may not be necessary. It should be noted that dilution depends on infiltration which is a function of the permeability of the soil. For soils of low permeability such as dense clay, infiltration rates are low and lot sizes may have to be as large as 2.9 ha in order for the nitrate to be diluted to 10 mg/L at the lot boundary (Geo-Analysis Inc and Richards and Associates, 1992).

If the lot is smaller than 1 ha, then the degree of isolation between the proposed septic system and an existing or potential aquifer must be determined. Where it can be demonstrated that the septic system is isolated from an aquifer, step three is not necessary. If isolation cannot be demonstrated, a hydrogeologic study must predict the potential cumulative impact of the individual septic systems on the groundwater at the site boundary.

The third step of assessing potential impact should be conducted by considering the following:

i) nitrate as the critical contaminant at a concentration of 10 mg/L;
ii) average daily flows of 1000 L/day into each septic system; and
iii) a concentration of 40 mg/L of nitrate in domestic effluent.

It should be stressed that this is an interim guideline and subject to change as more information and technologies become available (Ontario Ministry of the Environment, 1992c).

5.8.3.2 Technical Guideline for Water Supply Assessment for Subdivision Developments on Individual Private Wells

The objectives of this guideline are to provide the technical guidance for consultants to assess groundwater quality and quantity and to ensure that all development proposals involving individual well water supplies are submitted with a hydrogeological study. The goal is to ensure that future residents of homes on individual private wells have adequate supplies of good quality water.

The primary component of the water supply assessment is the determination of groundwater quantity and quality. If wells do not exist on the site then test wells, which can be used later as supply wells, must be drilled. The number and spacing of test wells must be sufficient to adequately determine the quantity and quality of groundwater as well as the hydrogeology of the site.

The water quantity assessment must establish that sufficient water can be supplied for normal domestic requirements. A minimum pumping rate of 13.7 L/min for a duration of six hours is recommended for conducting pumping tests on each of the test wells. If groundwater heat pumps are to be used, then the amount required by them must be added to the minimum pumping rate. If the matter of groundwater heat pumps is not addressed in the assessment, the MOEE will request that a condition be placed on the subdivision agreement indicating that the area is not approved for groundwater heat pumps.

Near the end of each pumping test, a water sample must be taken to determine the chemical and bacteriological quality of the water. The health and aesthetic parameters to be analyzed are listed (see Appendix B). Land uses within 500 m of the site must be investigated to determine if additional parameters such as heavy metals or pesticides must be added to the list.

The recommendation from the MOEE will be determined by the following:

i) Where health and aesthetic criteria are met, MOEE will recommend approval of the proposed development.

ii) Where health criteria are not met, MOEE will recommend against approval of the proposal.

iii) Where health criteria are met but aesthetic objectives are exceeded, it may be possible to use in-home water treatment systems to reduce the values of the aesthetic parameters to a level below the limits and thereby meet the objectives. However, it is the municipality's responsibility to decide whether development on the basis of in-home treatment systems should be allowed.

As a condition of approval the MOEE will require that the recommendations of the hydrogeological assessment are incorporated in the final agreement between the municipality and the developer (Ontario Ministry of the Environment, 1992d)

5.3.4 Draft Report of the Commission on Planning and Development Reform in Ontario

The Commission on Planning and Development Reform in Ontario was appointed by the Minister of Municipal Affairs in June 1991. It was given a broad mandate to recommend changes to the Planning Act and related policies. Among the issues and reforms investigated by the Commission, one of the most important was considering the natural environment at the beginning of the planning process.

In its draft report of December 1992, the Commission recommended a set of policy statements that would eventually be adopted under the Planning Act. The policy statement related to protection of groundwater quality was entitled "Natural Heritage and Ecosystem Protection and Restoration". The goal of this policy statement is to "protect the quality and integrity of ecosystems, including air, water, land, and biota; and, where quality and integrity have been diminished, to restore or remediate to healthy conditions" (Commission on Planning and Development Reform, 1992, p. 23).

The goal is to be achieved through a set of 12 objectives, some of which directly relate to groundwater protection. The first two objectives in the following list are major components of a groundwater protection strategy. The third statement relates to soil and groundwater cleanup of contaminated sites.

i) Development will be permitted only if the quantity and quality of water in groundwater and surface water systems are not adversely affected in the short and long term.

ii) ...areas of natural and scientific interest and groundwater recharge areas will be identified and classified into areas where (a) no development is permitted or (b) development may be permitted if it does not adversely affect the features and functions for which the area is identified.

iii) The need to remediate contaminated air, water and soil, their systems and contaminated sites will be determined, and an appropriate plan for site remediation will be prepared and implemented before structural building permits are issued.

Other objectives which may involve groundwater quality and quantity protection are related to significant wetlands and adjacent lands and to regionally significant ravines.

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7.0 CONTACTS AND SOURCES OF INFORMATION (OTHER THAN REFERENCES)

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7.1.2.1 Environmental Assessment Branch

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7.1.4 Regional Operations Division

7.1.4.1 Spills Action Centre

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7.1.4.3 The Regional Offices

REGION 1 - SOUTHWESTERN

London Regional Office
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(519) 661-2200

Owen Sound District Office
1180-20th Street East
OWEN SOUND, Ont.
(519) 371-2901

Sarnia District Office
Suite 109, 265 Front St North
SARNIA, Ont.
(519) 336-4030

Windsor District Office
6th Floor, 250 Windsor Ave
WINDSOR, Ont.
(519) 254-2546

Technical Assessment Section

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Blaigie Novakovic, Hydrogeologist	(519) 661-2200

REGION 2 - WEST CENTRAL

Hamilton Regional Office
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Cambridge District Office
400 Clyde Road
CAMBRIDGE, Ont.
(519) 653-1511

Welland District Office
637-641 Niagara Street North
WELLAND, Ont.
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REGION 3 - CENTRAL

Toronto Regional Office
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Halton-Peel District Office
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OAKVILLE, Ont.
(416) 844-5747

Peterborough District Office
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Cornwall District Office
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Sault Ste. Marie District Office
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7.4.1 Fuel Safety Branch

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7.7.1 Environmental Office

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7.7.2 Legal Services Branch

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APPENDIX A

ONTARIO MUNICIPALITIES WITH A POPULATION GREATER THAN 1000 SUPPLIED BY GROUNDWATER

DATA FROM THE MUNICIPAL (WATER) USE DATABASE

TABLE A-1 SOUTHWESTERN REGION MUNICIPALITIES

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
WOODSTOCK	89/11/17	28000	28000	18269
STRATFORD	89/11/17	27700	27500	15867
OWEN SOUND	90/02/26	20000	19913	15546
STRATHROY	90/02/23	10000	10000	6524
INGERSOLL	89/11/17	9000	9000	6117
TILLSONBURG	89/11/17	11500	11500	5910
LISTOWEL	89/11/17	5250	5200	4050
WALKERTON	90/09/06	4700	4588	3533
ST.MARYS	89/11/17	5069	4866	3410
TECUMSEH TWP.	86/11/05	7731	6364	3000
AYLMER, ONT.	89/11/17	5528	5500	2990
WINGHAM	86/11/05	3000	3000	2258
MITCHELL	X______X	2992	2992	2241
WASAGA BEACH	90/02/26	5124	4650	2217
CLINTON	X______X	3124	3124	1968
BLANDFORD-BLEINHEIM TWP.	89/11/17	6731	575	1932
WESTMINISTER TWP.	90/02/23	5932	3000	1800
DURHAM	90/09/06	2318	2318	1334
RIDGETOWN	89/11/17	3200	3200	1200
SEAFORTH	X______X	2148	2148	1185
ZORRA TWP.	87/08/06	8098	2800	1185
NORTH DORCHESTER TWP.	90/02/23	6983	3000	1137
STEPHEN TWP.	90/09/06	4164	3123	1111
NORWICH TWP.	89/11/17	9526	3255	1055
CHESLEY	X______X	1841	1841	936
MARKDALE	X______X	1226	1214	809
FOREST	X______X	2658	2392	774
LUCAN	90/09/06	1800	1742	716

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
CARADOC TWP.	90/02/23	5525	2536	650
DUNDALK	X______X	1295	1295	549
HENSALL	90/02/23	1155	1155	532
LONDON TWP.	90/02/23	5841	900	500
BELMONT VLG.	89/11/17	1155	1155	453
LUCKNOW	X______X	1062	1062	439
TEESWATER	X______X	1000	1000	390
MILVERTON	90/09/06	1500	1500	330
LOBO TWP.	90/09/06	4927	300	265
MALAHIDE TWP.	89/11/17	5387	550	250
DELAWARE TWP.	90/02/23	2192	600	250

TABLE A-2 NORTHEASTERN REGION MUNICIPALITIES

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
VALLEY EAST	86/11/06	21000	21000	6400
KAPUSKASING	X______X	11378	10695	4643
NEW LISKEARD	X______X	5286	5286	3029
RAYSIDE-BALFOUR	86/11/06	14231	7150	2855
COCHRANE	90/02/27	4500	4500	2728
ONAPING FALLS	86/11/06	5619	4677	2679
CAPREOL	86/11/06	3352	3352	2611
MATTAWA	X______X	2535	2535	2231
BLIND RIVER	90/02/27	3263	3263	1591
ENGLEHART	X______X	1740	1740	907
SOUTH RIVER	X______X	1072	1072	324

TABLE A-3 CENTRAL REGION MUNICIPALITIES

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
VAUGHAN	89/11/08	95000	92000	45000
BARRIE	90/02/26	50000	50000	31883
WHITBY	89/11/07	50400	47000	22884
RICHMOND HILL	86/10/07	46700	43000	21046
HALTON HILLS	89/11/15	42553	31569	15327
NEWMARKET	90/09/06	39000	38000	12973
AURORA	86/10/07	21000	18001	11991
MIDLAND	90/02/27	12500	12500	8637
MILTON	89/11/15	38282	31656	8065
BRADFORD	90/02/26	8825	8825	5532
ALLISTON	90/02/26	7000	7000	4500
PENETANGUISHENE	90/09/06	5800	5800	4184
EAST GWILLIMBURY	89/11/09	14000	11000	3100
WHITCHURCH STOUFFVILLE	89/11/09	17000	9000	3015
CALEDON	86/10/10	27100	7500	2417
BROCK TWP.	89/11/08	10003	5620	2400
SCUGOG TWP.	89/11/08	15205	7456	2230
KING TWP.	86/10/07	18000	7200	2055
BRIGHTON	X______X	3595	3500	1960
TOTTENHAM	90/02/26	3500	3500	1818
UXBRIDGE TWP.	89/11/08	11895	4126	1700
STAYNER	X______X	2868	2868	1397
COLBORNE VLG.	89/11/07	1849	1849	1377
BEETON	90/02/26	2170	2170	923
ELMVALE	X______X	1476	1476	855
BRANTFORD TWP.	89/11/17	6477	660	730
NORWOOD	90/09/06	1250	1250	668
VESPRA TWP.	90/02/26	5843	641	651

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
INNISFIL TWP.	90/02/26	13573	1200	554
COOKSTOWN	89/11/08	1027	1027	520
ESSA TWP.	90/02/26	13321	1119	500
HAVELOCK	X______X	1381	1381	483
COLDWATER	90/02/26	1084	900	436
CREEMORE	X______X	1190	904	362
ORILLIA TWP.	90/02/26	7175	700	120
ORO TWP.	90/02/26	7528	546	71
W.GWILLIMBURY	90/02/26	4283	50	30

TABLE A-4 SOUTHEASTERN REGION MUNICIPALITIES

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
ALMONTE	89/10/03	4240	4065	1633
KEMPTVILLE	88/09/29	2597	2597	1558
CLARENCE TWP.	86/09/18	7516	2600	1495
WINCHESTER VLG.	86/09/18	2180	2100	1309
FRANKFORD	X______X	2040	1612	1218
STIRLING	89/11/06	1900	1900	1100
WELLINGTON	89/11/07	1500	1500	656
MADOC VLG.	X______X	1255	1000	593
L'ORIGNAL	86/09/18	1914	1500	553
VANKLEEK HILL	X______X	1775	1775	530
CHESTERVILLE	89/10/01	1498	1460	527
TWEED	X______X	1559	1559	512
RIDEAU TWP.	89/10/01	10271	900	450
ALFRED VLG.	X______X	1030	979	303
WEST CARLETON TWP.	89/10/01	11828	300	50

TABLE A-5 WEST CENTRAL REGION MUNICIPALITIES

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
KITCHENER	89/11/17	150000	150000	77282
CAMBRIDGE	86/11/04	80728	77434	38709
WATERLOO	89/11/17	73000	73000	30913
ORANGEVILLE	89/11/09	16707	16707	8219
SIMCOE	89/11/17	14290	4717	8140
NANTICOKE	89/11/17	20202	3678	7455
WOOLWICH TWP.	86/11/05	16732	8538	6088
PARIS	89/11/17	8100	7800	5936
PELHAM	90/02/28	11100	8715	5501
HALDIMAND	89/11/15	17701	2914	4707
FERGUS	89/11/15	7000	7000	4319
MOUNT FOREST	86/11/03	3780	3600	2278
HARRISTON	X______X	1993	1893	1295
ELORA	88/09/30	2799	2799	1154
SHELBURNE	X______X	2972	2972	1094
PALMERSTON	89/11/15	2200	2200	886
ARTHUR	90/09/06	1800	1800	822
FLAMBOROUGH	86/11/04	26142	3137	766
ERIN VLG.	X______X	2320	2111	668
GUELPH TWP.	89/11/09	3014	300	173

TABLE A-6 NORTHWESTERN REGION MUNICIPALITY

MUNICIPALITY	DATE REVISED	POPULATION (1989)	POPULATION SERVED WATER	TOTAL CONSUMPTION (m^3/day)
MARATHON	90/02/27	5000	5000	3200

APPENDIX B

GROUNDWATER PARAMETER TABLES

TABLE B-1 HEALTH-RELATED BACTERIOLOGICAL PARAMETERS

PARAMETER	DRINKING WATER QUALITY LIMIT	COMMENTS
Escherichia coli	0	Indicators of contamination
Fecal coliforms	0	
Total coliforms	<5	Indicator of possible or potential contamination

TABLE B-2 HEALTH-RELATED CHEMICAL AND PHYSICAL PARAMETERS

PARAMETER	DRINKING WATER QUALITY LIMIT	COMMENTS
Fluoride	1.5 mg/L	Exceedence may cause fluorosis
Nitrate	10.0 mg/L	Contamination indicator; exceedance may be dangerous to infants and others.
Nitrite	1.0 mg/L	Contamination indicator
Nitrate plus Nitrite	10.0 mg/L	Contamination indicators
Turbidity	1 FTU*	Could indicate problems in well construction or a naturally occurring problem; may interfere with water treatment.
Sodium	200 mg/L	Levels may be significant for persons with medical conditions requiring low-salt diets.

* Formazin Turbidity Units

TABLE B-3 COMMON AESTHETIC, ANALYTICAL AND INDICATOR PARAMETERS

PARAMETER	GENERAL COMMENTS	DRINKING WATER QUALITY LIMIT	MAXIMUM CONCENTRATION (considered treatable)	COMMENTS ON TREATMENT
Alkalinity	useful analytical parameter	-	-	-
Ammonia	contamination indicators	-	-	-
Background Bacteria				
Calcium	see Hardness	-	-	-
Chloride	associated with salt problems	250 mg/L	250 mg/L	not considered reasonably treatable above limit
Colour	associated with certain metals and organic substances	5 TCU*	7 TCU	carbon filter treatment systems
Conductivity	useful analytical parameter	-	-	-
Hardness	taste, encrustation and reaction with soap	500 mg/L as $CaCO_3$	-	water softener
Iron	may cause staining of plumbing fixtures and laundry	0.3 mg/L	up to 5.0 mg/L	water softeners or manganese greensand filters
			5.0 to 10.0 mg/L	oxidation with filtration
Magnesium	see Hardness			
Manganese	may cause staining of plumbing fixtures and laundry	0.05 mg/L	1.0 mg/L	water softeners or manganese greensand filters
Methane	stimulates organic fouling; explosive if accumulates	absence	absence	not considered reasonably treatable
pH	associated with corrosion or encrustation or contamination by other substances	6.5-8.5	-	-
Phenol	taste and odour, esp. after chlorination	0.002 mg/L	0.05 mg/L	chlorination followed by carbon filtration

PARAMETER	GENERAL COMMENTS	DRINKING WATER QUALITY LIMIT	MAXIMUM CONCENTRATION (considered treatable)	COMMENTS ON TREATMENT
Sulphate	laxative	500 mg/L	500 mg/L	not considered reasonably treatable above the limit
Sulphide	taste, odour, staining; determine on fresh sample	0.05 mg/L as hydrogen sulphide	0.3 mg/L	chlorination
			1.0 mg/L	proprietary filter media
			2.5 mg/L	manganese greensand filter
Tannins	contamination indicator	-	-	-
TDS (Total Dissolved Solids)	Corrosion or encrustation of metal fixtures or appliances; taste; must be measured independently of conductivity	500 mg/L	-	requires written rationale that corrosion, encrustation or taste will not occur
TOC (Total Organic Carbon)	may contribute to contamination by other substances	5.0 mg/L as C	10.0 mg/L as C	carbon filtration

* TCU = True Colour Unit

APPENDIX C

ONTARIO'S DRINKING WATER OBJECTIVES

ONTARIO MINISTRY OF THE ENVIRONMENT

SUMMER 1992

The primary purpose of Ontario's Drinking Water Objectives is to protect public health. Water for human consumption should contain neither disease-causing organisms nor hazardous concentrations of toxic chemicals or radioactive substances. The drinking water objectives have been derived from the best available information. Almost all objectives are based on the consumption of 1.5 litres of water per day by a 70-kilogram person for 70 years.

Maximum Acceptable Concentrations (MAC) are health-related objectives established for substances which could affect people's health. The length of time the MAC may be exceeded without injury to health depends on the nature and concentration of the contaminant. No drinking water can be permitted to exceed these objectives continuously. The local medical officer of health, who acts under the authority of the Health Promotion and Protection Act, is responsible for judgements concerning human health.

Interim Maximum Acceptable Concentrations (IMAC) are health-related objectives established for substances when there is insufficient toxicological data to establish a MAC with reasonable certainty. When it is not feasible for practical reasons to establish a MAC at a desired level, an interim objective may be established at an achievable level.

Aesthetic Objectives (AO) are established for substances which may impair the taste, smell or colour of water or which may interfere with good water quality control practices.

Ontario's drinking water objectives apply to all water supply systems that provide water for domestic purposes and serve more than five private residences or are capable of supplying more than 50,000 litres of water a day.

Operational Guidelines (OG) are established for parameters which need to be controlled to ensure efficient treatment of the water.

TABLE C-1 OBJECTIVES FOR HEALTH-RELATED PARAMETERS

PARAMETER	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
Alachlor		.005	
Aldicarb	0.009		
Aldrin + Dieldrin	0.0007		
Arsenic		0.025	
Atrazine		0.06	
Azinphos-methyl	0.02		
Barium		1.0	
Bendiocarb	0.04		
Benzene	0.005		
Benzo(a)pyrene	0.00001		
Boron		5.0	
Bromoxynil		0.005	
Cadmium	0.005		
Carbaryl	0.09		

PARAMETER	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
Carbofuran	0.09		
Carbon Tetrachloride	0.005		
Chlordane	0.007		
Chlorpyrifos	0.09		
Chromium	0.05		
Cyanazine		0.01	
Cyanide	0.2		
Diazinon	0.02		
Dicamba	0.12		
1,2-Dichlorobenzene			0.003
1,4-Dichlorobenzene	0.005		0.001
Dichlorodiphenyltri-chloroethane (DDT) and metabolites	0.03		
1,2-Dichloroethane		0.005	
Dichloromethane	0.05		
2,4-Dichlorophenol	0.9		0.0003
2,4-Dichlorophenoxy acetic-acid (2,4-D)	0.1		
Diclofop-methyl	0.009		
Dimethoate		0.02	
Dioxins and Furans		0.000000015	
Diquat	0.07		
Diuron	0.15		
Flouride	1.5		
Glyphosate		0.28	
Heptachlor and Heptachlor Epoxide	0.003		
Lead	0.01		
Lindane	0.004		
Malathion	0.19		
Mercury	0.001		
Methoxychlor	0.9		
Metolachlor		0.05	

PARAMETER	MAC (mg/L)	IMAC (mg/L)	AO (mg/L)
Metribuzin	0.08		
Monochlorobenzene	0.08		0.03
Nitrate (N)	10.0		
Nitrite (N)	1.0		
Nitrate + Nitrite (N)	10.0		
Nitrilotriacetic Acid	0.4		
Nitrosodimethylamine (NDMA)		0.000009	
Paraquat		0.01	
Parathion	0.05		
Pentachlorophenol	0.06		0.03
Phorate		0.002	
Picloram		0.19	
Polychlorinated Biphenyls (PCBs)		0.003	
Prometryne		0.001	
Selenium	0.01		
Simazine		0.01	
Temephos		0.28	
Terbufos		0.001	
2,3,4,6-Tetrachloro-phenol	0.1		0.001
Triallate	0.23		
Trichloroethylene	0.05		
2,4,6-Trichlorophenol	0.005		0.002
2,4,5-Trichlorophenoxy-acetic Acid (2,4,5-T)	0.28		0.02
Trifluralin		0.045	
Trihalomethanes	0.35		
Turbidity	1 NTU*		5 NTU
Uranium	0.1		

* NTU = Nephelometric Turbidity Unit

TABLE C-2 CHEMICAL/PHYSICAL OBJECTIVES (NOT HEALTH-RELATED)

PARAMETER	OBJECTIVE (mg/L-unless otherwise stated)	TYPE OF OBJECTIVE
Alkalinity (as $CaCO_3$)	30-500	Operational Guideline
Aluminum	0.1	Operational Guideline
Chloride	250	Aesthetic Objective
Colour	5 TCU	Aesthetic Objective
Copper	1.0	Aesthetic Objective
Dissolved Organic Carbon	5.0	Aesthetic Objective
Ethylbenzene	0.0024	Aesthetic Objective
Hardness (as $CaCo_3$)	80-100	Operational Guideline
Iron	0.3	Aesthetic Objective
Manganese	0.05	Aesthetic Objective
Methane	3 L/m^3	Aesthetic Objective
Odour	Inoffensive	Aesthetic Objective
Organic Nitrogen	0.15	Operational Guideline
pH	6.5-8.5(unitless)	Operational Guideline
Sodium	200[a]	Aesthetic Objective
Sulphate	500[b]	Aesthetic Objective
Sulphide	0.05	Aesthetic Objective
Taste	Inoffensive	Aesthetic Objective
Temperature	15°C	Aesthetic Objective
Toluene	0.024	Aesthetic Objective
Total Dissolved Solids	500	Aesthetic Objective
Xylenes	0.3	Aesthetic Objective
Zinc	5.0	Aesthetic Objective

[a] Sodium levels which exceed 20 mg/L may be of interest or concern to doctors who wish to prescribe sodium-restricted diets for their patients.

[b] When sulphate levels exceed 500 mg/L water may have a laxative effect on some people.

TABLE C-3 MICROBIOLOGICAL OBJECTIVES

PARAMETER	Maximum Acceptable Concentration (counts/100 mL)	AESTHETIC OBJECTIVE
Total Coliforms	5	
Fecal Coliforms	0	
Escherichia coli	0	
Heterotrophic Plate Count		500/mL

Occasionally levels of less than five per 100 millilitres (mL) of total coliform bacteria may occur in some distribution systems and may be indicative of poor, but not unsafe water quality.

Where more than 5 total coliform bacteria per 100 mL are detected in a single sample, or where consecutive or multiple samples from a distribution system are positive for total coliform bacteria, repeat samples ("special samples") must be taken as soon as possible. Should any of the repeat samples show the presence of total coliform bacteria, the local medical officer of health must be notified and corrective action should be initiated immediately.

The detection of either fecal coliforms or *Escherichia coli* (E. coli) in a distribution system necessitates immediate resampling. The local medical officer of health must be notified and corrective action taken as required.

TABLE C-4 RADIONUCLIDES

PARAMETER	MAC (Becquerels/L)
Cesium-137	50
Iodine-131	10
Radium-236	1
Strontium-90	10
Tritium	40,000